JOURNAL

of the

AMERICAN WELDING SOCIETY

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33 West Thirty-ninth Street, New York

Subscription $10.00 per year to United States. $11.00 to Canada. Libraries $5.00.
Back numbers, per copy: Members, $0.50; Non members, $1.00.

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AMERICAN WELDING SOCIETY
ESTABLISHED 1919
JOURNAL

Volume 9 February, 1930 Number 2

Journal Bound Volumes

Members of the Society who desire to have bound their individual issues of the JOURNAL in permanent book form with black imitation leather covers may do so by sending copies of the twelve issues to Russell-Rutter Co., 461 Eighth Avenue, New York, N. Y.

A charge of $1.50 will be billed directly by the American Welding Society.

This arrangement expires March 5, 1930.

Membership in the Society

In April the American Welding Society will be eleven years old. It started out with a membership of about a hundred and it has grown to the extent that it now has 1150 members.

The American Welding Society offers (1) An opportunity for personal association with the leaders of the industry and exchange of information and ideas. (2) Means to keep informed up to date on the latest developments in the welding field. (3) Opportunity to assist through cooperative effort in increasing the knowledge of welding and extending its applications. (4) Assisting in the development and use of codes and standards.

These are ample reasons for becoming identified with the American Welding Society.

With the complexity of modern industry it is necessary for people working in the same field to get together, as progress can be best made through such cooperative effort rather than by individual genius. The committee work of the Society, the section activities, the presentation of papers and research work, offers the best opportunity for the members to contribute to the advancement of welding. Members of the Society who participate in some phase of its work and give up their time, their knowledge and their experience have the satisfaction of knowing that they are contributing something to our national well-being.

It is necessary that the work of the Society be conducted on a high plane of dignity and free from the stain of commercialism. We all, therefore, have a justified feeling of pride in seeing our Society grow in membership and accomplishment, and realize that we have all had a share in it.

Senior Engineer (Welding)

Recently the United States Civil Service Commission announced an open competitive examination for the position of senior welding engineer. The duties of this position as listed in the commission's announcement of the examination are as follows:

"To extend the application of welding in the construction of naval vessels; to keep in touch with the latest developments in the industrial field of welding; to have general oversight over the welding processes at navy yards with a view to coordinating and perfecting their methods; to initiate tests and research and to analyze the results of experiments; to prepare specifications for and advise as to the selection and purchase of welding appliances and materials; to criticize design and detailed structural plans of naval vessels as affecting and as affected by the application of welding, and in general to advise the Bureau of Construction and Repair, Navy Department, on all matters pertaining to the application of welding to ship construction."

The résumé of the prerequisites for this position is quoted also in part as follows:

"In addition (to a college or university degree in engineering), must

show that they have had at least six years of extended professional experience in engineering, consistent with the duties of the position, at least three years of which were of a responsible supervisory or administrative character, in which the applicant has been engaged in the direction or performance of important mechanical engineering work including research and development in connection with the industrial application of modern methods of welding. Such experience must indicate outstanding professional attainment and proved research and executive ability of a high order, and must show a high degree of progression in duties, responsibilities, etc."

The most significant thing in this announcement is that the entrance salary for this position in Washington is the highest entrance salary paid to any engineer under the United States Civil Service. Those interested in the progress of welding may view with satisfaction the attitude of the United States Government toward this field of engineering. The great strides made by welding in recent years in the whole industrial field have made it a vital and nearly universal method of joining metals in all lines of fabrication and repair. The importance which the Government now attaches to the profession of welding engineering may be regarded as another step forward in the growing general confidence in and enthusiasm for welding.

Obituary

At a meeting of the Executive Committee of the American Welding Society held in the Engineering Societies Building, New York, N. Y., on the 4th day of February, 1930, the following resolutions on the death of Sherwood F. Jeter were adopted:

Whereas: The American Welding Society has learned with profound sorrow of the sudden and unexpected death on December 31, 1929, of Sherwood F. Jeter, vice-president of the Hartford Steam Boiler Inspection and Insurance Company, and

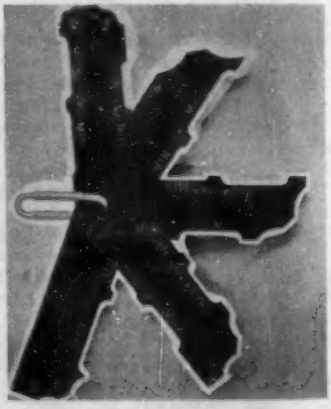
Whereas: In the death of Sherwood F. Jeter the American Welding Society has lost a sincere friend and a loyal co-worker for the advancement of the welding industry; therefore, be it

Resolved: That the members of the American Welding Society, through its Executive Committee, hereby express their deep regret and great sense of loss in the death of Sherwood F. Jeter, and further be it

Resolved: That these resolutions be spread upon the records of the Society and a copy sent to Mrs. Jeter, the Boiler Code Committee of the American Society of Mechanical Engineers and to the president of the Hartford Steam Boiler Inspection and Insurance Company as an expression of our mutual loss and sympathy.

Standardization of Gauges

The Committee on Standardization of Gauges has, for some time, carefully considered the problem assigned to it. A number of different types of gauges were proposed and considered. Because of lack of agreement on these various types proposed it was recommended by the committee that for the present the gauges shown in Section C of the Structural Steel Welding Committee's Bulletin be recommended



for general use in industry. A description of these gauges was published on pages 28 to 33 of the November, 1928, issue of the JOURNAL of the American Welding Society. The Society is advised that the General Electric Company has made up gauges according to these specifications which are available at $1.60 per set. As soon as other manufacturers report that they are in a position to supply these gauges, notice of that fact will be published.

SECTION ACTIVITIES

Boston

The February meeting of the Boston Section was held on the 14th. Mr. J. F. Lincoln of the Lincoln Electric Company spoke on "Some Recent Developments in the Application of Welding to Replace Casting." This was a very interesting subject and a lively discussion followed.

Chicago

The January meeting of the American Welding Society, Chicago Section, was held on Thursday, Jan. 9, at the Greer School of Automotive Engineering, 2024 S. Wabash Avenue. The subject of the program was the "Welding of Monel Metal and Stainless Steel." In spite of the fact that the two previous days had witnessed one of the worst storms of the winter, the meeting room was filled to capacity. The program was given by M. E. Olsen, welding supervisor of Mojonnier Brothers Co., Chicago, manufacturers of milk machinery. The subject was introduced by a motion picture showing this equipment in actual use and illustrating how it puts the dairy business on a mass production basis and also how essential it is that such equipment offer the greatest possible opportunities for a thorough cleaning. Mr. Olsen then gave a talk in which he explained the reason for using monel metal and stainless steel in various kinds of equipment and the reasons for welding. He then explained the technique used in welding both of these materals with the electric arc and with the oxy-acetylene torch. A series of lantern slides giving an opportunity to study some of these applications concluded the talk. Then the meeting adjourned to the shop where the Greer students receive their shop instruction in welding, and these welding processes were demonstrated by Mr. Olsen. Interest in all the features of the meeting was very high, particularly in the practical aspects of the subject.

Cleveland

The Cleveland Section held a meeting on Jan. 17 with attendance of about seventy-five. Motion pictures and paper were presented by Mr. A. F. Davis of the Lincoln Electric Company on "Arc Welding Oil and Gas Lines."

Detroit

The next meeting of this Section will be held on Feb. 26 as a joint meeting with the Industrial Electrical Engineering Society at the Masonic Temple. Mr. W. H. Zorn, of the Detroit Edison Company, will speak on the subject "Welding in the Modern Power Plant." His lecture will deal particularly with the various phases of welding which were carried on in the new Delray Power Plant of The Detroit Edison Company.

Plans are being carried out to have the meeting following the February meeting with the Automotive Engineering Society with a speaker well qualified to describe the various welding processes carried on in the manufacture of automobiles.

Philadelphia

The Philadelphia Section held a joint meeting with the American Society of Steel Treaters on Feb. 17. Dr. Gilbert E. Doan, of the Naval Research Laboratories, Anacostia, D. C., spoke on "Scientific Progress in Welding." Mr. J. J. Crowe, of the Air Reduction Sales Co., spoke on "Cutting by the Oxy-Acetylene Process," which dealt with the chemistry and metallography of the process.

San Francisco

Another excellent program was arranged for the Jan. 24th meeting of this Section, which was held in the class rooms of The Boeing School of Aeronautics, Oakland Airport. Mr. H. F. Lusk, dean of the Boeing School, spoke on the subject, "Welding as Applied to Airplane Construction." Mr. Mouton, local representative of the United States Department of Commerce, presented the Department of Commerce requirements and viewpoint on "Welding in Airplane Construction and Maintenance."

Western New York

The regular monthly meeting was held on Feb. 10, which was a joint meeting with the A.S.M.E., A.S.C.E., A.I.E.E., S.A.E., A.S.H. & V.E. and the Engineering Society of Buffalo. Mr. A. M. Candy, of the Westinghouse Electric & Mfg. Co., spoke on "Application of Arc Welding to Steel Structures and Machinery Design."

The meetings for the balance of this season will be as follows:

March 10, 1930—Air Reduction Sales Company. Speaker to be announced later.
Subject: Pipe Welding in Buildings.

April 17, 1930—Annual meeting for election of officers. At this meeting a buffet supper will be served to the members and there will be a general conference of all members to talk over the increased activities of the Section for the ensuing season of 1930-31.

May 26, 1930—Metal & Thermit Corporation. Speaker to be announced later. At this meeting there will be an actual demonstration of thermit welding and also a paper explaining this wonderful process of welding.

With the exception of the Annual Meeting on April 17, all meetings will be held jointly with the A.S.M.E., A.S.C.E., A.I.E.E., S.A.E., A.S.H. & V.E. and the Engineering Society of Buffalo.

Los Angeles

A meeting of the prominent members of the Los Angeles Section of the American Welding Society was held in the office of the chairman, Mr. W. A. F. Millinger, on Feb. 4, for the purpose of discussing ways and means of putting before the proper authorities methods of welding structural steel buildings and their inspection, and to formulate the program for the coming meetings.

New York

A joint meeting of the New York Section was held with the American Society for Steel Treating, New York Section, on Tuesday, Feb. 11. The subject for this meeting was "Destructive and Non-Destructive Tests for Proving the Worth of Welds." The speakers of the evening were Messrs. A. B. Kinzel and J. R. Dawson, of the Union Carbide and Carbon Research Laboratories, Inc. Messrs. Kinzel and Dawson in their paper presented a critical discussion of the methods of testing and the significance of test results. They covered tensile, bend and fatigue testing, as well as non-destructive tests by means of the stethoscope, x-ray, electric conductivity, etc. This was followed by a discussion and demonstration of the portable tensile testing machine and stethoscopic method of testing.

EMPLOYMENT SERVICE BULLETIN

Opportunities.—The Society is glad to learn of desirable opportunities from responsible sources, announcements of which will be published without charge in the BULLETIN.

Services Available.—Under this heading brief announcements (not more than seventy-five words in length) will be published without charge to members. Announcements will not be repeated except upon request received after an interval of three months; during this period, names and records will remain in the office reference files.

Note.—Copy for publication in the BULLETIN should reach the Society's Office not later than the thirtieth of the month if publication in the following issue is desired. *ALL REPLIES should be addressed to the number indicated in each case and mailed to Society headquarters.*

POSITIONS VACANT

V-47. Foreman who is familiar with railroad work for job in Russia. The man should be familiar with Gas and Arc Welding and will be expected to sign a contract for not less than one year. Salary approximately $6,000 a year. Transportation back and forth for man and wife guaranteed.

SERVICES AVAILABLE

A-89. Engineer desires position. Age 29, married. Graduated from Oregon State College in M.E. Sales, B. F. Sturtevant Co., San Francisco, Westinghouse Elec. & Mfg. Co. Sales course, Arcos, Inc. Sent to Europe three months studying welding in Belgium, France, Switzerland and England; 18 months engineer demonstration, and sales covering all states east of Mississippi River. Would like welding engineer work. Any location either in United States or South America.

A-90. Welder desires position. Has had fifteen years' experience at Electric and Gas Welding and Cutting. Can furnish references.

Arc Welded Jigs, Fixtures and Machine Tools*

J. R. WEAVER †

IN presenting the above subject, I am not going to try to demonstrate welding in any respect but I wish to discuss the application of welding to the building of jigs, fixtures and machine tools. This particular application was practically forced upon us about a year ago due to the fact that it was necessary to manufacture this particular line of product on very short delivery. Our business increased very rapidly about that time so that in order to obtain all advantages possible in manufacturing, it was

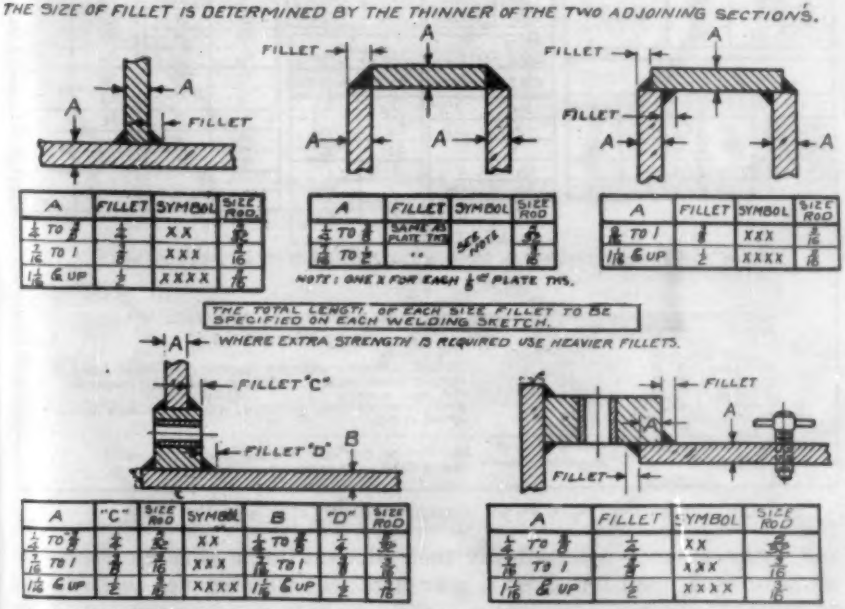

THE SIZE OF FILLET IS DETERMINED BY THE THINNER OF THE TWO ADJOINING SECTIONS.
FILLET
A
NOTE: ONE X FOR EACH 1/8" PLATE THS.
THE TOTAL LENGTH OF EACH SIZE FILLET TO BE SPECIFIED ON EACH WELDING SKETCH.
WHERE EXTRA STRENGTH IS REQUIRED USE HEAVIER FILLETS.
FILLET "C"
FILLET "D"
B
ALLOWABLE STRESS UNDER SHOCK IS 8000 LB. PER SQ. IN. = 1/8 STRENGTH OF STEEL.

FIG. 1—WELDS—SIZE OF BEADS

necessary to obtain jigs, fixtures, and special machine tools on short notice.

It was quite noticeable on new machine tools purchased from the machine tool manufacturers that invariably in all cases delay was due to time necessary to make the jigs and fixtures. Naturally, the machine tool was more or less of a standard product and could be delivered on com-

*Paper presented at New York Section Meeting, A. W. S., January 7.

†Superintendent, Manufacturing Equipment Department, Westinghouse Electric & Manufacturing Company.

paratively short time. However, in all cases when there was a delay, it was due to jigs and fixtures.

When the idea was conceived to manufacture jigs and fixtures from structural shapes welded together, we built several of these jigs and put them through a very thorough test to ascertain whether they would be suitable for our work. We naturally tried these jigs for all the inaccuracies that are liable to occur due to warpage, distortion, etc., and then decided upon a definite program of manufacture which has given us extremely satisfactory results. The thought was advanced that the jigs

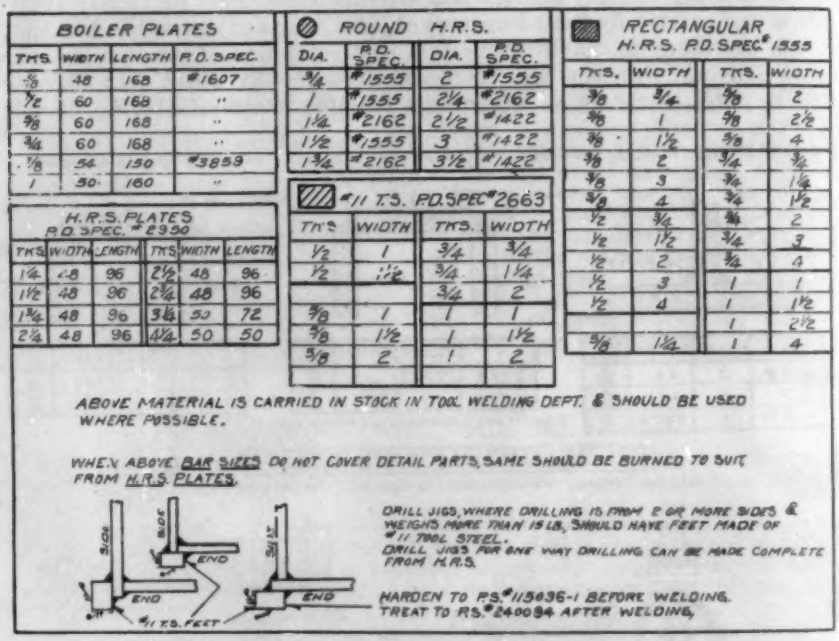

BOILER PLATES
THS. WIDTH LENGTH P.D. SPEC.
5/8 48 168 #1607
1/2 60 168 "
9/8 60 168 "
3/4 60 168 "
7/8 54 150 #3859
1 50 160 "
H.R.S. PLATES P.D. SPEC. #2930
THS. WIDTH LENGTH THS. WIDTH LENGTH
1/4 48 96 2 1/2 48 96
1 1/2 48 96 2 3/4 48 96
1 3/4 48 96 3 3/4 50 72
2 1/4 48 96 4 1/4 50 50
ROUND H.R.S.
DIA. P.D. SPEC. DIA. P.D. SPEC.
3/4 #1555 2 #1555
1 #1555 2 1/4 #2162
1 1/4 #2162 2 1/2 #1422
1 1/2 #1555 3 #1422
1 3/4 #2162 3 1/2 #1422
#11 T.S. P.D. SPEC #2663
THS WIDTH THS. WIDTH
1/2 1 3/4 3/4
1/2 1 1/2 3/4 1 1/4
3/4 2
5/8 1 1 1
5/8 1 1/2 1 1 1/2
5/8 2 1 2
RECTANGULAR H.R.S. P.D. SPEC. #1555
THS. WIDTH THS. WIDTH
5/8 3/4 5/8 2
5/8 1 5/8 2 1/2
5/8 1 1/2 5/8 4
5/8 2 3/4 3/4
5/8 3 3/4 1 1/4
5/8 4 3/4 1 1/2
1/2 3/4 3/4 2
1/2 1 1/2 3/4 3
1/2 2 3/4 4
1/2 3 1 1
1/2 4 1 1 1/2
1 2 1/2
5/8 1 1/4 1 4
ABOVE MATERIAL IS CARRIED IN STOCK IN TOOL WELDING DEPT. & SHOULD BE USED WHERE POSSIBLE.
WHEN ABOVE BAR SIZES DO NOT COVER DETAIL PARTS, SAME SHOULD BE BURNED TO SUIT FROM H.R.S. PLATES.
SIDE
END
SIDE
END
#11 T.S. FEET
DRILL JIGS, WHERE DRILLING IS FROM 2 OR MORE SIDES & WEIGHS MORE THAN 15 LB, SHOULD HAVE FEET MADE OF #11 TOOL STEEL.
DRILL JIGS FOR ONE WAY DRILLING CAN BE MADE COMPLETE FROM H.R.S.
HARDEN TO P.S. #115036-1 BEFORE WELDING.
TREAT TO P.S. #240094 AFTER WELDING.

FIG. 2—MATERIAL TO BE USED IN WELDED JIGS AND FIXTURES

and fixtures would not maintain their shape after a period of time but we have used them for about a year with less maintenance than we had with cast iron jigs.

As I mentioned above, we found it necessary to obtain jigs, fixtures and machine tools on very short notice and, in checking our deliveries of cast jigs versus structural jigs, we found that when putting the orders through for cast jigs in the regular way, it required about four weeks to obtain our castings. Of course, it was necessary to make patterns, core boxes, etc. The castings had to be cast, cleaned, etc., before being sent to the shop. We find that with the welded structure, we can obtain the most complicated jig in not more than one week's time. The average time is about four days and you can readily appreciate what a decided advantage this is in manufacture of any kind of product.

These jigs are made from hot rolled steel of whatever shapes and sizes

are necessary and welded together. Where hardened pieces are required, these are made from tool steel, hardened and attached to the jigs by means of screws, bolts, etc., or, in a case of bushings, pressed in holes provided for them. We experienced some trouble with the feet on these jigs due to the fact that after the jig was annealed, these feet were too soft so that chips on machine tools would imbed themselves in these feet. In order to overcome this, we made the feet from tool steel and heat treated them before welding to the jig. These feet are then drawn to a scleroscope

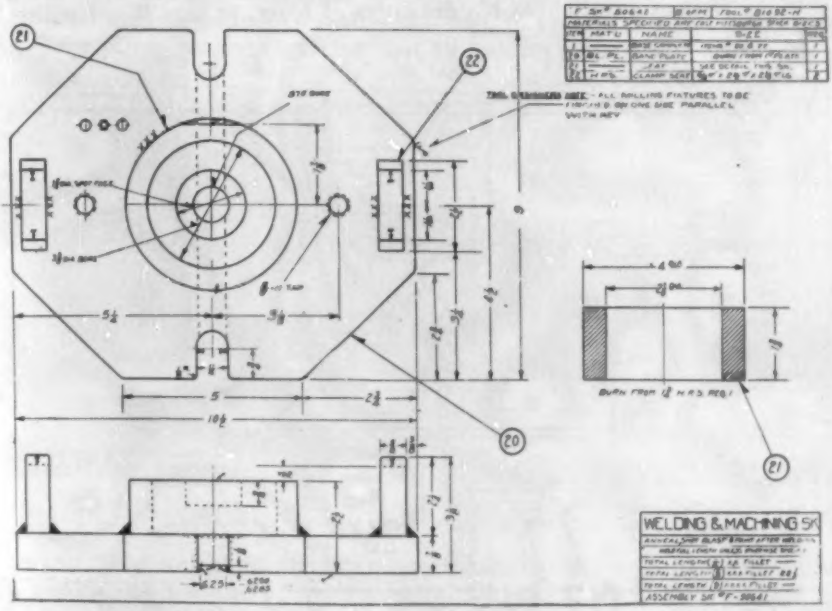


FIG. 3

hardness of 45 to 50 and are of sufficient hardness but they still can be machined. The results have been very satisfactory.

Of course, it was necessary, when we adapted welded jigs and fixtures, to change our entire method of manufacturing jigs, fixtures and machine tools. This not only included the actual manufacture of these jigs and fixtures in the shop, but also in designing them. In order to have the proper information on the drawings, it was necessary to train our tool designers in the art of welding to such an extent that they could put the proper information on the sketches which were sent to the shop. In order to do this, we incorporated in our standard book, several sheets of instruction which, in addition to supplying the workmen in the shop with information, also standardized the manufacture of welded jigs and fixtures.

Figure 1 shows the various type of welds and the size of bead which is used on welded jigs and fixtures. This is a standard throughout our shop

so that the workman is familiar with it and any reference to it is readily understood.

In order to avoid delays due to material being out of stock, we have listed in our standard book a sheet showing the standard stock size of steel that are being used for this particular method of manufacture.

Figure 2 shows such a sheet and, as you will note, it gives the sizes of bar and plate stock. When bar stock is not suitable, the part is cut to size from a plate by means of an acetylene torch.

When the designer makes his drawings of a jig, he lays it out without

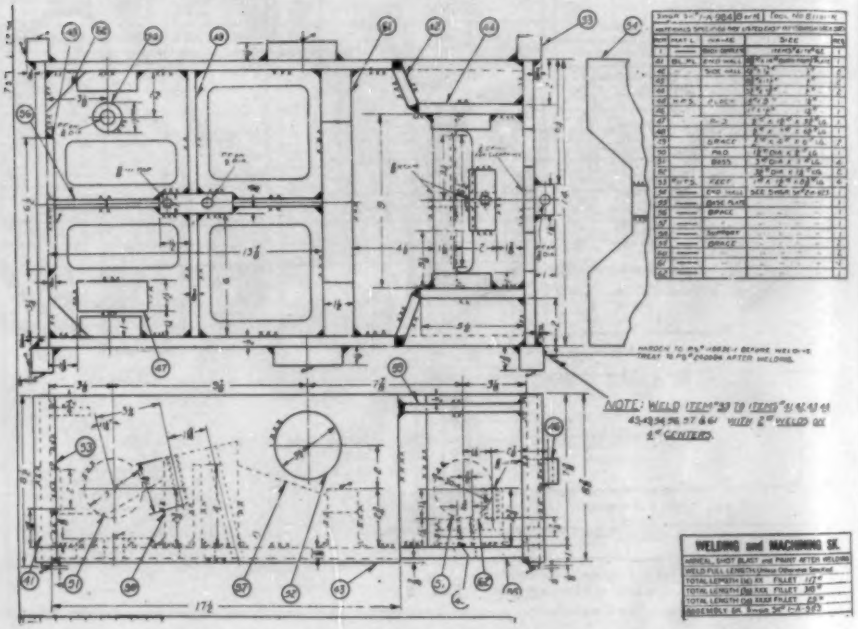


FIG. 4

showing any particular method of construction. Therefore, it is necessary for the tool designer to make a separate sketch, which is shown in Figure 3, and is called a welding and machining sketch. You will note this gives the detail construction and indicates in the bill of material what material is to be ordered and from the drawing can be obtained the information as to the shape desired. This material is then cut from the proper sized material with a saw as in the case of bar stock, or with acetylene torch, as in the case of a plate. The parts are then assembled and welded together, which I will explain later on, but I wish to call your attention to the title on this sketch, which indicates the total length of a certain size weld necessary to completely weld this jig. This is done for the convenience of the Time Study Supervisor who estimates and sets a value on the time it should take to manufacture this jig.

In order to give you more of an idea as to the extent which we give

information to the shop, Figure 4 shows more in detail the various parts of a jig and the method of assembling and machining. The various sections are shown separately on a separate sheet so the shop will have no trouble to obtain the material and cut it to the proper shape and size. Figure 4 also is used for machining purposes, giving the necessary dimensions, etc., that are required to properly machine this jig.

Of course, the question has come up frequently that it is not possible to test a weld without destroying it and the workman must be relied upon for good workmanship. We realize this and, in order to control this phase of the welding, we are requiring that all welders stamp their work with a

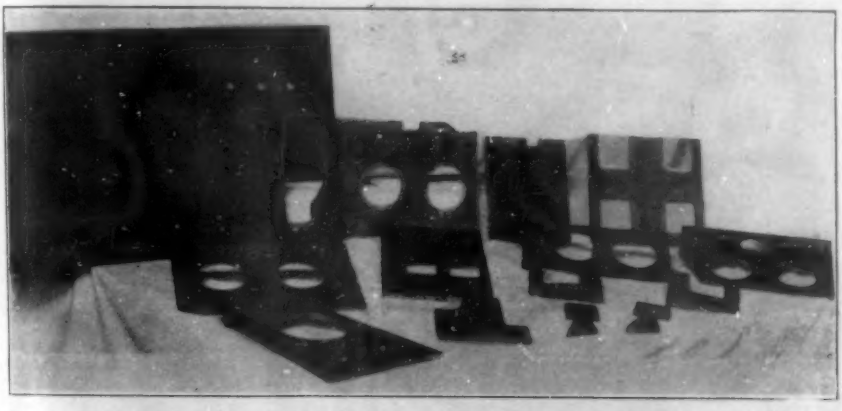


FIG. 5—VARIOUS DETAILS AS CUT WITH THE TORCH, SHOWING ALSO ONE SIDE MARKED OFF, AND DRILLED HOLES FOR STARTING THE CUT

stencil. This stencil identifies the particular welder who performed the work and, in case there is any question, it can be readily traced back to the man who did the welding.

Periodically, we run a test on welds and if we discover any welding that is not satisfactory, the workman is required to take additional instruction, or if he proves entirely unsatisfactory, he is taken off the job.

In the above, I have discussed the method of preparing sketches by the tool designers and now I will try to tell and show you how the jigs are actually manufactured.

Figure 5 shows a number of parts cut by a gas cutting machine to size to make a jig. You will note that all the necessary large holes are cut by means of an acetylene torch in the plates before they are assembled into a jig.

These various detail parts are assembled by a mechanic and tack welded just sufficiently to hold these parts together. This is done by a mechanic so that the parts are properly located, also so that the jig is squared up and is a good job when it is finally finished. After the tack welding, the jig is passed to a welder who completes the job by welding the jig as it should be.

Figure 6 shows a jig tacked together ready for the welder.

Figure 7 shows a jig completely welded and you will note that this jig is fairly large; however, it only weighs 120 lb. It is used for drilling the bracket which is shown at the right of the jig.

The fact that these jigs are made from hot rolled steel and the welding distracts somewhat from the appearance of the completed jig, also certain strains due to the welding must be removed from the jig so it maintains its shape and size. In order to overcome these conditions, we normalize all welded jigs in order to remove strains. This is done by heating the jigs in a furnace to a temperature of 1000 deg., after which they are

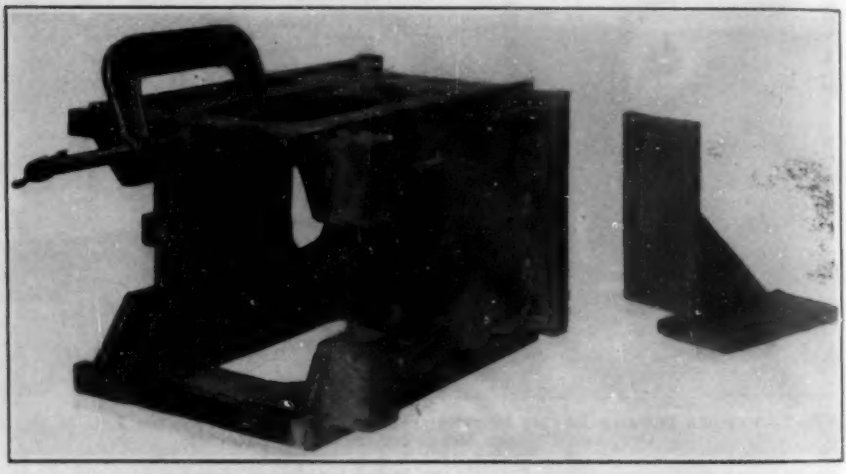


FIG. 6—SHOWING CLAMP HOLDING TOOL STEEL FOOT IN PLACE FOR TACK WELDING. A SQUARING OR SETTING UP ANGLE IS SHOWN AT RIGHT

Feet made from tool steel S.A.E. Specifications 6150 (0.45-0.55 carbon). They are hardened before welding and annealed by heating to 1000 deg. Fahr. after welding

FIG. 7—BODY OF DRILL JIG FOR BRACKET FOR TALKING MOVIE MACHINE. THIS JIG IS 15 IN. X 23 IN. X 12½ IN. HIGH AND WEIGHS ONLY 120 LB. BRACKET SHOWN AT RIGHT

allowed to cool in the air. Due to the use of hot rolled steel and the normalizing, a certain amount of scale is present on these jigs so it is necessary to remove it. This is done by means of a sand blast machine. The appearance of the jig is greatly improved by the sand blasting operations. After the sand blasting operation, the jigs are spray painted. The jig is sent to the shop for regular machining and the machining is no different

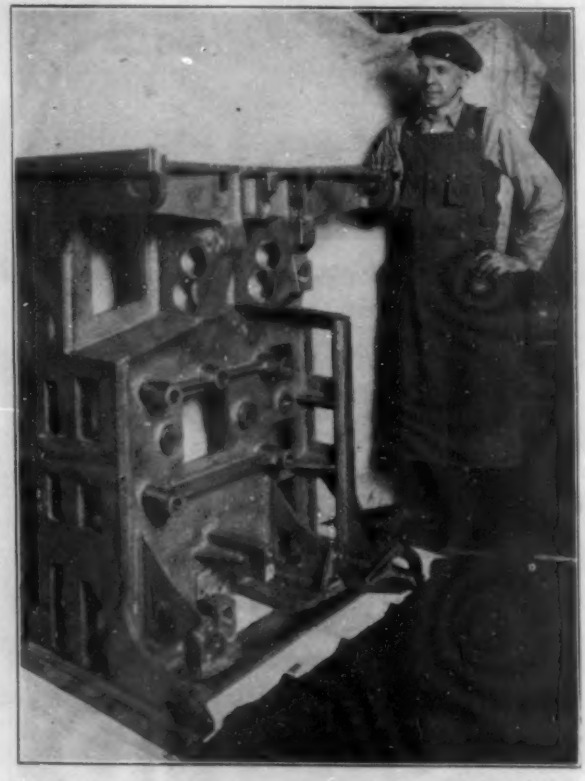


FIG. 8—FRONT VIEW OF DRILL JIG FOR MAIN BASE OF OIL CIR. BREAKER. WEIGHT 1304 LB. 39½ IN. X 51½ IN. X 21 IN.

than it would be for a cast jig except that there isn't as much material allowed for finish as is ordinarily allowed on castings.

To give you an idea as to what extent we have gone on the welding of jigs and fixtures, I am showing in Figures 8 and 9 a jig weighing 1300 lb., the overall dimension being 39½ x 51½ x 21 inches. You will note that this is a complicated jig and, in order to make a casting, it would take considerable time, both in the pattern shop and in the foundry. This jig is built entirely of steel using hot rolled bar stock and plates. I wish to call your attention particularly to the bosses shown in Figure 8 which are made from hot rolled round steel cut off with a saw and welded in place.

Figure 10 shows welded jig being used on a drill press. We have experienced no difficulty in these jigs due to inaccuracies, although we have been using them for approximately a year.

Figure 11 shows a different type of jig that we have manufactured which will indicate to you that it is feasible to make any kind of a jig necessary by this method.

In addition to the above, we had the advantage of considerably more

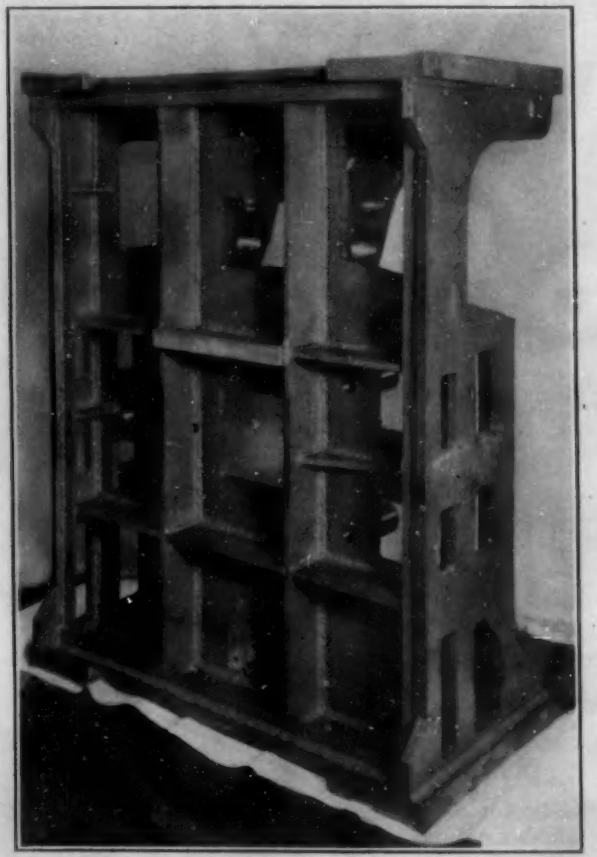


FIG. 9—REAR VIEW OF DRILL JIG FOR MAIN BASE OF OIL CIRCUIT BREAKER

strength and less weight with a jig made from steel. This is due to the fact that the jig can be made from thinner material and it is not necessary to increase the sections to reduce casting difficulties, etc. It is also possible to place metal where it is most desired in order to make a stronger jig with the least amount of weight. Also, in case there should happen to be a change in the jig required, due to the product being changed, or for

any other reason, it is very easy to remove any interference by means of an acetylene torch and reweld the parts in new locations if desired.

I wish further to call your attention to another application and that is the design of special machine tools from the same construction. We have applied this method of construction only to special machine tools such as

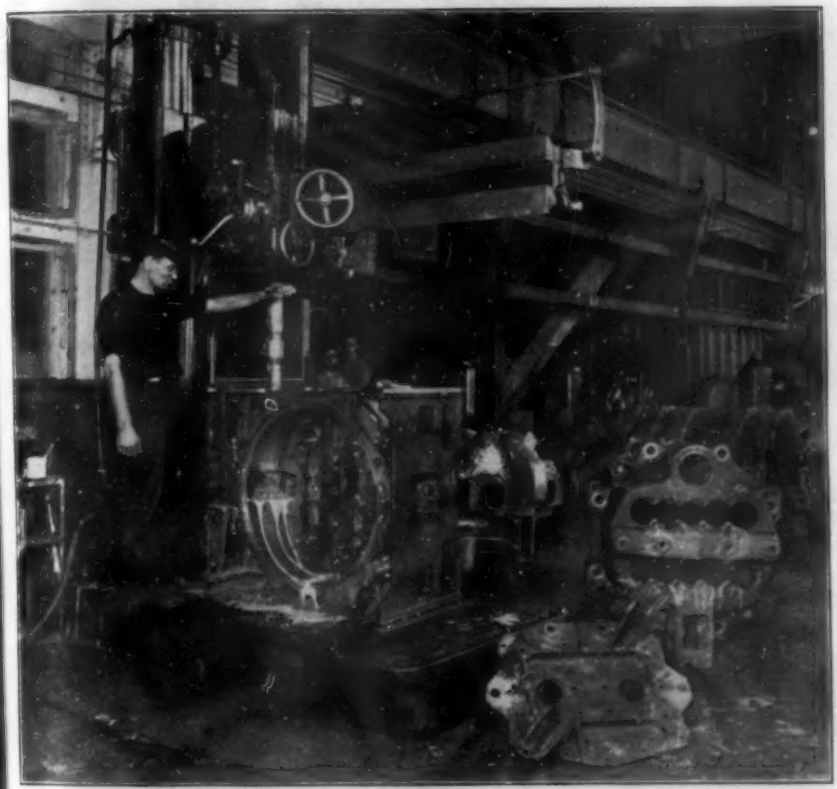


FIG. 10—JIG IN USE

we design and build ourselves; however, I believe it will be applied to all types of machines in the future. The machine shown in Figure 12 is a double head oxygen acetylene cutting machine. It was necessary to design a machine that would cut either straight or bevel edges of various thicknesses of steel. The machine was so constructed that one man could operate both heads as the controls are so arranged to be convenient from one position. This particular structure for this machine worked out very satisfactorily and we had no trouble due to misalignment, vibration, or any of the things that may be found in the machines which are not properly designed or built.

Figure 13 shows winding machines for winding mush type coils for AC

motors. This machine is entirely fabricated from structural steel and welded together and I wish to call your attention in particular to the construction of the tail stock. You will note this is somewhat similar to the general design of tail stocks with the exception that this is welded from structural steel. It functions satisfactorily and, although the requirements

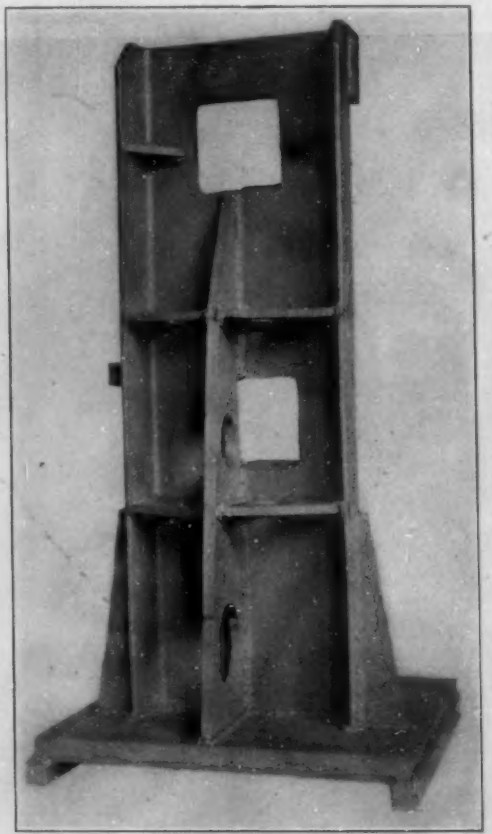


FIG. 11—REAR VIEW DRILLING AND LINE REAMING FIXTURE FOR BEARINGS ON CROSS BAR FOR LARGE OIL CIRCUIT BREAKER. 16½ IN. SQ. BASE X 32 IN. HIGH

are not as rigid as they would be on metal cutting machines, I do not see any reason why it could not be adapted satisfactorily.

I realize that some further development would be necessary before this particular type of construction can be applied to the general machine tool construction. I am calling these particular facts to your attention because I believe these are successfully demonstrated in our shop and show the practicability of welded jigs, fixtures and machine tools, and structural steel welded together which obtains a decided advantage from several angles. I am building from 200 to 400 welded jigs and from three to six

special machines per month. I have been able to build these tools in shorter time and have reduced the average cost approximately 25 per cent. I have been able to produce a jig and fixture that I believe would be more desirable, due to the fact that it is lighter, and at the same time, of at least equal strength. The jigs and fixtures which have been built in

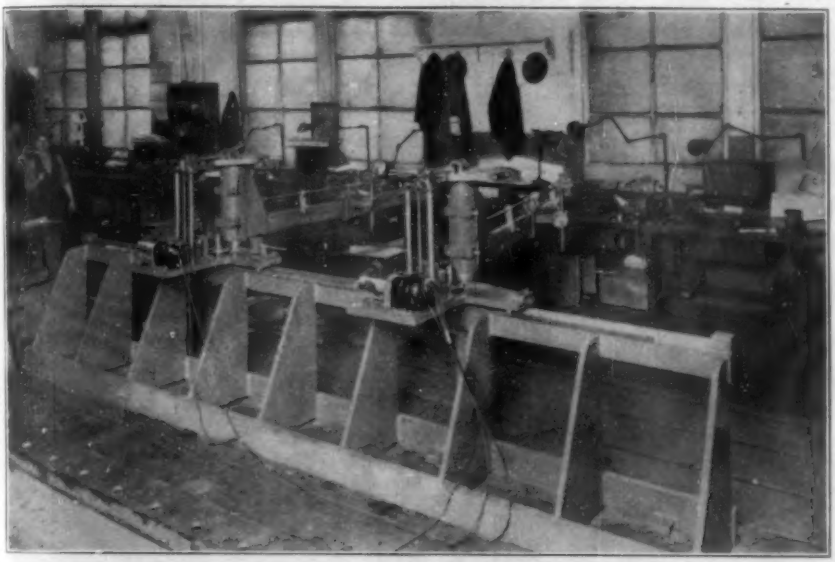


FIG. 12—THE MACHINE SHOWN IS A DOUBLE HEAD OXYGEN ACETYLENE CUTTING MACHINE

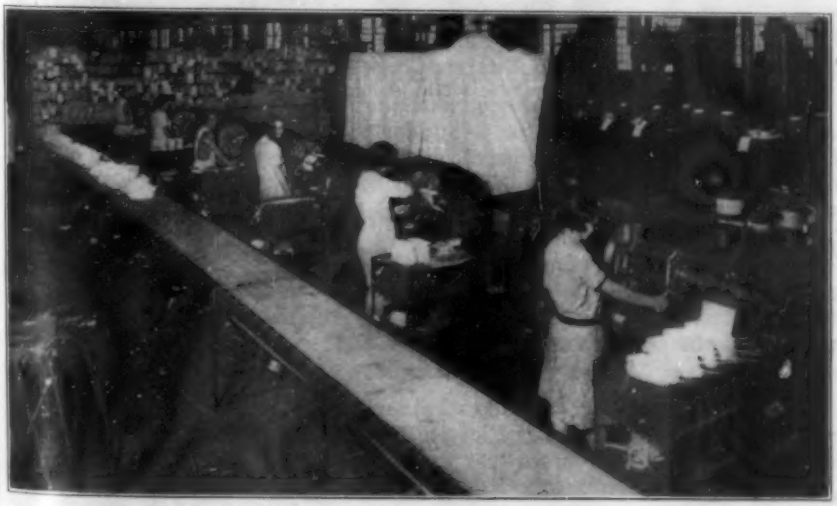


FIG. 13—SHOWS WINDING MACHINES FOR WINDING MUSH TYPE COILS FOR AC MOTORS

this way have required less maintenance. I do not think we have sacrificed anything due to misalignment, warpage, distortion, vibration, etc., and we have not taken anything from the appearance on this particular type of equipment. I am calling these things to your attention so you may take advantage of them in whatever way you can in your respective manufacture. I believe it is a practical idea and, due to the advantages mentioned above, it should be given serious consideration.

Strengthening Bridges and Structures by Welding*

A. G. LEAKE †

WE are all familiar with riveting of structural steel and the cost of various types of riveted joints.

About seven years ago our company became interested in electric welding, and in our experience we have found that properly designed with the proper welding equipment and properly trained operators, any structural joint can be welded, in most cases, from 30 to 50 per cent cheaper than it can be riveted.

We have also found that in making bridge repairs, in which we are specializing, new members can be added to the old structure for reinforcement more conveniently and more economically by this method, and without interruption to traffic. This is illustrated in some of the photographs.

Inasmuch as electric welding is comparatively new, of course, engineers are sceptical because they have no experience to guide them, and I find it very difficult to sell arc welded projects to engineers and architects, not because they do not believe it is as strong as riveting but because they have no proof and I can only refer them to work which we have previously executed, or to tests which have been made by the American Welding Society, the American Bridge Co., the Westinghouse Electric & Manufacturing Co., and the General Electric Co.

However, there is no question but that we must all eventually adapt ourselves to arc welding, for a builder can purchase a structural steel frame designed for welding much cheaper than he can a riveted structure because the detailing of welded work is much cheaper than riveted. Even assuming there is no difference, after the details leave the drafting room for the shop, 50 per cent of the laying out, and practically all of the punching and templets are eliminated. Furthermore, if in designing buildings engineers can eliminate from 15 to 20 per cent of the weight necessary in a riveted structure, particularly if there is considerable tonnage involved, as well as the cost of riveting in the field, are not these worthwhile savings?

I have stated that arc welding of structural steel is cheaper than riveting, although I know that the larger fabricators will not agree with me,

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*Paper presented at Joint Meeting of A. W. S. and A. S. C. E., New York Sections, Nov. 20.

†President, Leake and Nelson Company.

and at the present time this may be true, because they have not thoroughly equipped their shops for welding nor have they enough trained operators to supply the demand if it were decided to design arc welded projects extensively in the near future.

Another important advantage of welding is the elimination of the noise from the pneumatic riveting hammers, which, as you all know, is exceedingly nerve racking. Perhaps some of you have had occasion to add new sections to columns already in a building and it was necessary to drill holes and rivet plates and angles to the column to increase the section.

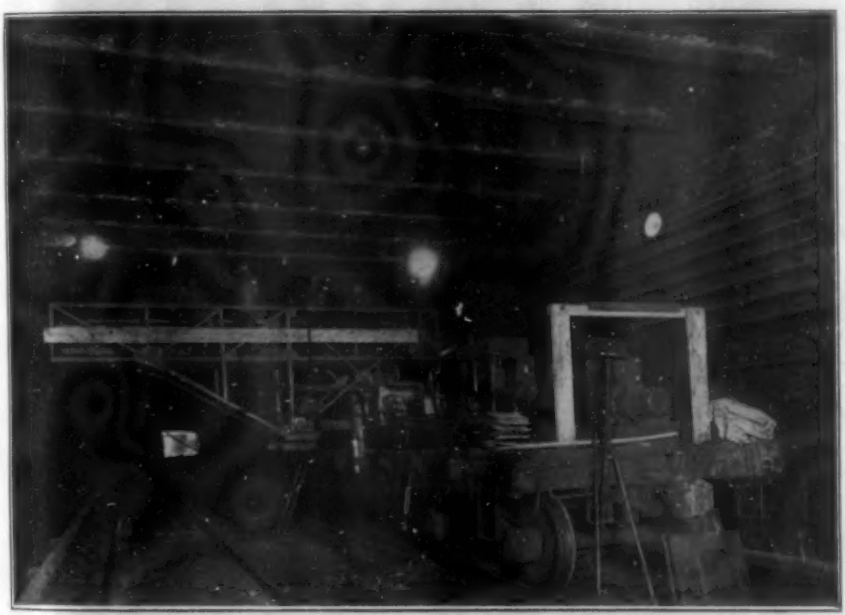

FIG. 1—REPAIRS TO NEW YORK CENTRAL RAILROAD BRIDGE. REINFORCING STRUCTURAL MEMBERS UNDER LOADS OBTAINING THE REQUIRED INITIAL STRESS

If the building is occupied, even though the section which you are reinforcing is entirely inclosed or separated from the rest of the building, riveting makes it practically impossible for the tenants to conduct their business, so the work must be done after business hours, which, of course, means additional expense for overtime work. Whereas if welding is employed it is only necessary to inclose the portion on which you are working and weld on the additional plates or angles required. This not only eliminates the drilling machine and the man to operate it, but four riveters as well. One arc welder takes the place of all these men.

No doubt you have all had occasion to replace a stiffener angle which has corroded or the web of a girder which has deteriorated, but the balance of the girder is in perfect condition, and I will show you how this can be done by arc welding.

Figure 1 shows workmen installing new cover plates on the bottom flange of girders of Bridge M-4-A, New York Central Railroad.

The revolving steel staging is entirely arc welded and permits operation of trains on adjacent tracks as it is only necessary to swing it around parallel with the car to allow trains to pass, then return it to its original position.

This project is very well described in detail in an article by H. T. Welty, Engineer of Structures in the *Engineering News-Record* of October 24.

FIG. 2—TRANSFER BRIDGE NO. 3, SHOWING PLATE WELDED AT THE SHORE END IN THE WEB OF THE BOTTOM CORD

Figure 2 is a view of the Transfer Bridge No. 3, New York Central Railroad, West 68th Street, New York City, and it is subjected to practically every known stress. It, therefore, affords an excellent opportunity to test welding. This view is of the bottom cord at the end where the cord was fractured and the new plate welded on both sections. This has been in service now for approximately six months and shows no failure. Figure 3 is a view of the bottom lateral system showing the new gusset

plate using the old lateral angles, welding in the old rivet holes to the new gusset plate, and along the edge of the angle. The floor beams were also treated in the same manner.

Figure 4 is an overhead structure carrying a highway over the New York Central tracks at Morris Heights Station. This, as you know, is an extremely busy location as all the main line trains of the New York Central pass directly under this structure. There is scant clearance over the stacks of the engines, the usual stack coming within 3 inches of the under

FIG. 3—TRANSFER BRIDGE NO. 3, SHOWING NEW GUSSET PLATES AND LATERAL ANGLE

side flanges. The view shows detail of the cover plate on the bottom flange of girder, repairs to the web of the girder, and repairs to stiffeners. I would like to call your attention to the stiffener angles. This section has been cut out and a new piece welded in and the toe of the angles seal welded to prevent further corrosion, and gives additional strength. You will note the new section is welded to the bottom flange of the girder which assures perfect bearing on the outstanding leg of the stiffener to the girder flanges both top and bottom. This also eliminates grinding the new part of the stiffener to fit the fillet of the angle.

These are the clamps which hold the plate in place until it has been completely welded to the bottom flange.

This is the new section of the web with slot welds 1 inch wide by 3 inches long in the center and the rivets on this line of the girder were not

disturbed but the plate was punched with holes slightly larger than the rivet heads in order to assure attachment of the new plate to the web of the girder and in addition we welded directly to the rivet heads, and you will appreciate that this circumferential value is much larger in cross section than of the rivet heads.

The clearance of the new section between here and the toe of the angle is ⅜ inches, and this section, as you see, is welded to the toe of the angle.

Along this vertical line we placed ⅜-inch welds at intervals of 3 inches, obtaining good penetration to the old web and the new section, seal welding between to prevent the entrance of water and other corrosive elements.

FIG. 4—MORRIS HEIGHTS BRIDGE OVER NEW YORK CENTRAL TRACKS, SHOWING NEW WEB MEMBERS WELDED TO THE GIRDERS. NOTE THE SLOT WELDS IN THE CENTER OF THE PLATE. ALSO STIFFENER ANGLES REPAIRED AT THE LOWER SECTION AND NEW COVER PLATE ON THE BOTTOM OF THE GIRDER. NOTE CLAMPS HOLDING PLATE

Figure 5 is a picture of Bridge No. 32.10 of the Erie Railroad. You will note the new plate which we installed on these web members, also additional plates in the web of the top cord, and the new plate welded on the bottom cord.

Figure 6 is a column base of a four-track viaduct of the Pennsylvania Railroad in Jersey City, which is approximately one mile long. This structure was built in 1898, and the majority of the column bases of the entire structure are in a condition similar to this one. We submitted a

proposal for new welded bases, were awarded the contract, and proceeded as follows: We erected this bent and four jacking struts with four one-hundred-ton jacks. This bent has been used where the new bases are required. At other points where it is only necessary to install new fillers,

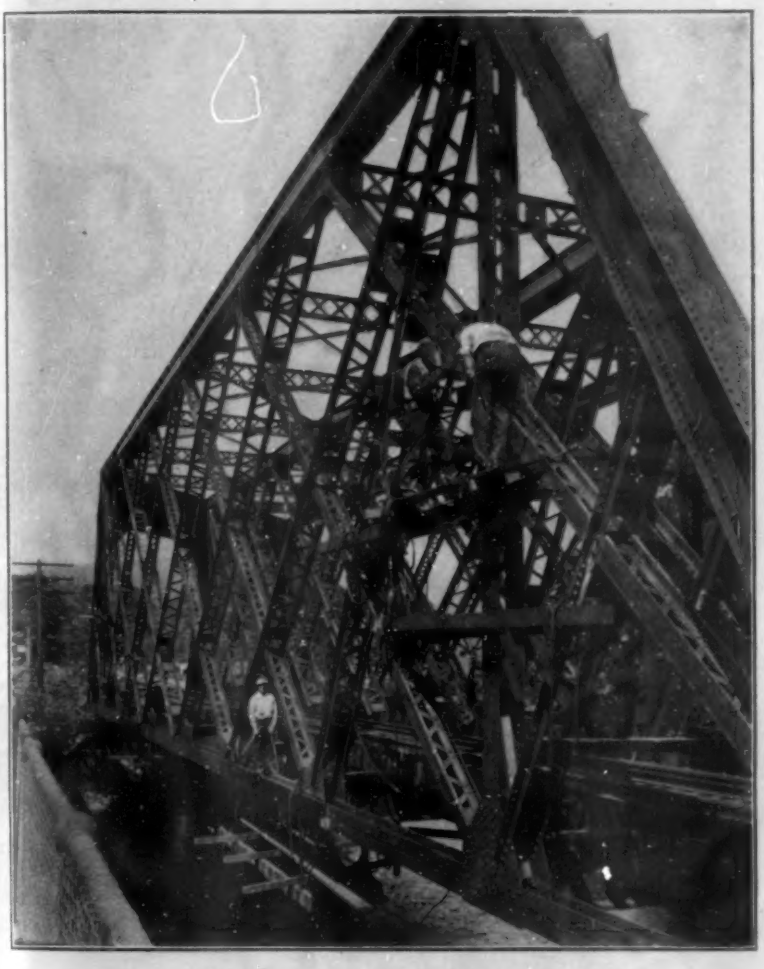

FIG. 5—BRIDGE OF ERIE RAILROAD

we only use the four jacking struts unless the required height is greater than 2 inches.

Figure 7 is the new welded base with new filler plates and new anchor bolts welded to the old one. This column base is entirely filled with concrete, so you can readily see how we underbid our competitors who estimated this project riveted as it would have been necessary for him to cut

FIG. 6—PRESENT CONDITION OF A COLUMN BASE OF PENNSYLVANIA RAILROAD

FIG. 7—A PORTION OF THE VIADUCT WITH NEW WELDED BASES

out all the concrete to remove these rivets and practically impossible to redrive all good rivets.

Returning to the new base, the rivets were cut off flush with this angle and the new plate was welded to the angle.

I would like to state in closing, that I cannot impress upon you too strongly the importance of placing welding contracts in the hands of experienced contractors who are well equipped not only with proper welding equipment and tools but with efficient, conscientious, dependable operators.

The Calorimetric Study of the Arc

By P. P. Alexander[1]

INTRODUCTION

THE total energy input to the arc can be accurately determined by means of the usual measuring instruments. However, when the electric arc is used as a tool for electric welding, it is useful to know not only the total energy in the arc, but also the distribution of that energy between the anode and cathode. This information is desirable for the purpose of determining the conditions for the most rapid melting of the electrode and for the effective fusing of the plates to be welded.

As has been shown by many physicists, the distribution of energy in the arc can be calculated. The heating of the cathode is due to the bombardment of its surface with positive ions which acquire a considerable velocity by moving through the cathode fall. This energy is increased a small amount by the heat of neutralization of these ions on the surface of the cathode, by a certain amount of heat evolved by oxidization reactions taking place either on its surface or in its vicinity, etc. The most important factors which determine the heating of the cathode are the ratio between the positive and negative ions in the immediate vicinity of the surface of the cathode, and the value of the cathode fall. These factors have been determined with precision for arcs maintained between non-vaporizing electrodes in such gases as helium, argon, and mercury, but corresponding values for an iron arc maintained in air are not known as yet with certainty. The anode is heated principally by the bombardment and by the absorption of released latent heat of condensation of the incoming electrons. We must also know for our calculations the value of the anode fall and the ratio between the electrons and the positive ions. However, at the present time, it is practically impossible to calculate with sufficient approximation the heat evolved at the cathode and the anode of a short iron arc of any considerable intensity.

The experimental method of determining the distribution of energy

[1] P. P. Alexander, Research Engineer, Thomson Research Laboratory of the General Electric Co., Lynn, Mass.

Presented at the Winter Convention of the A.I.E.E., New York, N. Y., Jan. 27-31, 1930.

in such an arc is, therefore, the only alternative. Although it cannot claim great precision, in the case of an iron arc of a type similar to that used in welding, it gives some useful information on this subject.

A great difficulty in making the necessary measurements is the inherent peculiarity of the iron welding arc. As the oscillogram in Fig. 1 shows, the voltage across the arc is a pulsating voltage of an average frequency of 300 cycles. When a molten globule passes across the arc from the rapidly melting electrode to the weld, the arc is momentarily short circuited and its voltage drops practically to zero.

Since the molten metal from the electrode is deposited into the opposite crater, all the energy consumed in melting the electrode is mechani-

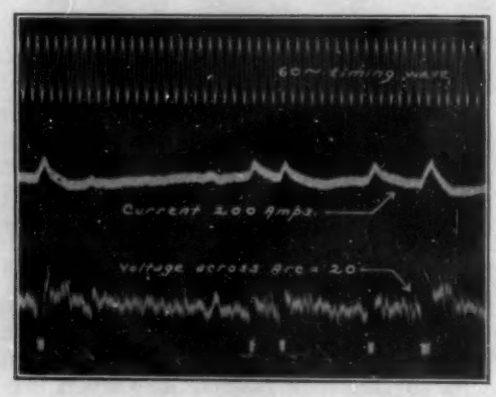

FIG. 1—OSCILLOGRAM OF ARC CURRENT AND VOLTAGE

cally transferred to this crater. In other words, the energies put into the cathode and the anode are periodically added together. Except for radiation and other losses, the total energy of the arc is eventually transferred into the weld. The speed of welding, however, depends not only on the total energy of the arc, but also on that part of the total energy of the arc which is utilized in melting the welding wire. In other words, it depends on the distribution of energy in the arc.

Experimental Method

As a first approach to the solution of this problem, the following method was developed to measure the ratio between the energy input of the anode and the cathode. The underlying thought in planning these experiments was to approach as near as possible to the conditions under which the iron arc is used as a welding tool and yet to eliminate all the unessential factors which might obstruct the solution of the problem. As has been mentioned above, one of these factors is the short circuiting of the arc by the molten globules.

The first series of tests, therefore, was conducted under conditions in which the short circuiting of the arc did not take place. As Fig. 2 shows, the anode and cathode consisted of small steel cylinders of identical shape and weight. They were polished to reduce the losses by

radiation and, except for the small surface at one end, were protected by an efficient heat insulation, consisting of a cushion of dry air inclosed in a cylinder of thin polished copper sheet. Near their outer ends

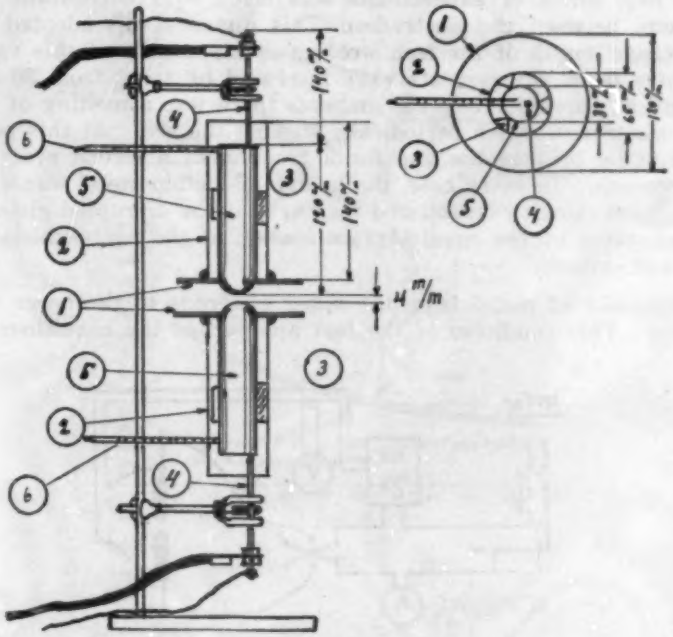

FIG. 2—ARC ELECTRODES USED IN TESTS

1. Asbestos, 3 mm. thick.
2. Cylinder of 0.12 mm. polished copper.
3. Cork spacer.
4. Brass rod.
5. Electrode, polished steel cylinder, 38 mm. in diameter.
6. Thermometer.

these electrodes were provided with holes on which thermometers of the same calibration as to heat capacity and sensitivity were inserted.

As Fig 3 shows, direct current was supplied by a constant potential source of 275 volts. A heavy resistance balance, supplemented by considerable reactance connected in series, insured a supply of current, practically independent of small variations in the voltage of the arc. Also, since the heat capacity and heat insulation of the anode and cathode were practically identical, variations of voltage and current in the arc during the observation would affect both electrodes equally. In other words, the error from this cause may be introduced in estimating the total input energy but not in determining the ratio between the energy input of the anode and cathode. The time of the burning of the arc was purposely made very short, ranging from 30 to 300 seconds. This resulted in a comparatively small temperature rise, and, therefore, small losses by radiation or conduction. In most of the experiments, the error as indicated by the difference between the total measured energy input

to the arc and the sum of the energy measured at the anode and at the cathode was less than 20 per cent, which indicates that these measurements were sufficiently exact for the purpose in view.

The first series of experiments was made with a constant distance of 4 mm. between the electrodes. This distance was adopted because the average length of the iron welding arc is usually of this value. In successive tests, the currents were increased by steps from 30 amperes up, until at approximately 135 amperes there was a melting of the tips of the electrodes, which periodically shorted the arc. At this point, the molten metal bridged the gap for a fraction of a second every two or three seconds. In every case, the bridge of molten metal was disrupted by the short circuit current, and the parts of the disrupted globule were then separated by the equal surface tension of the molten metal on the anode and cathode.

No transfer of metal from the upper electrode to the lower one was observed. This condition of the test approached the conditions met in

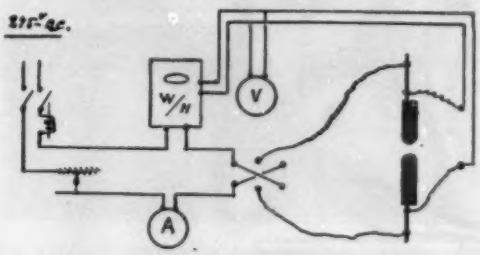

FIG. 3—CIRCUIT CONNECTIONS FOR TESTS

the metallic welding arc, yet did not contain the factors obscuring the real picture of the distribution of energy in the arc. The temperature curves shown in Figs. 4, 5 and 6 indicate that in all these experiments the energy delivered to the cathode was practically equal to that received by the anode.

Fig. 7 shows the temperature curves of the copper arc. The measured ratio between the anode and cathode energies was almost equal to one.

The second series of experiments was conducted for the purpose of determining the influence of the relative position of the anode and cathode on the distribution of energy in the carbon or iron-carbon arcs.

Table I gives the results of these measurements. The figures given in this table are not averages but are individual tests. However, prior to the tabulation of these results, every test was repeated several times and it was ascertained that the reported figures represent the most accurate observation for each type of arc.

The total energy developed in the arc was measured by counting the number of revolutions of the aluminum disk connected with the armature of the watthour meter. Since this instrument was specially calibrated

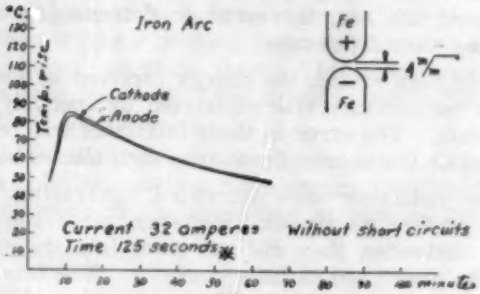

FIG. 4

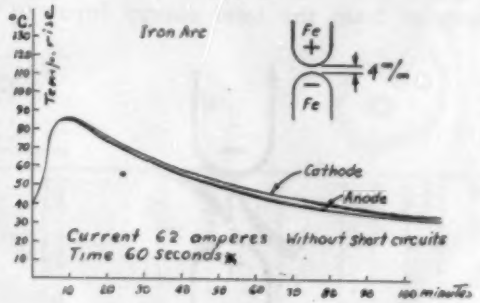

FIG. 5

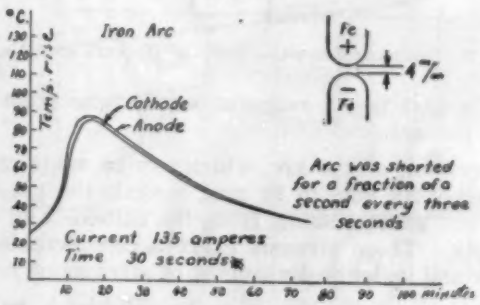

FIG. 6

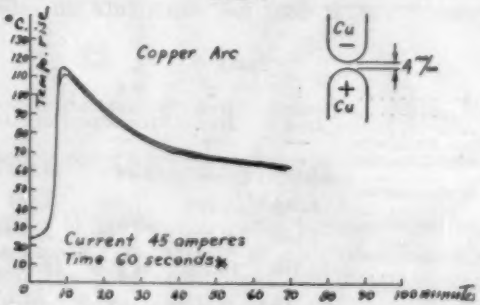

FIG. 7

FIGS. 4 TO 7—ANODE AND CATHODE TEMPERATURE CURVES

*Time of burning of the arc.

for the voltage of the arc, the error in determining the total energy was probably less than 1 per cent.

As has already been stated, the energy received by each electrode was estimated from temperature rise registered by specially calibrated mercury thermometers. The error in these estimates was probably less than 0.3 of 1 per cent of the energy input into each electrode.

The losses by radiation were estimated by tracing the temperature curves for the cooling electrodes. However, since the losses were the same for both electrodes, they did not enter into the calculation of the ratio between the anode and cathode energies. The total losses from the arc shown in Table I were obtained by subtracting the measured anode and cathode energies from the total energy input to the arc. These

FIG. 8—DRAWING SHOWING HOT GAS BLASTS AND ARC CORE

losses are due in part to the evaporation of atoms from the cathode and anode spots of the arc.

A close observation of the arc, which can be made more conveniently with longer arcs of 10 mm. to 12 mm., reveals the presence of two distinct blasts of hot gases issuing from the cathode and anode with considerable velocity. These streams exert a considerable repulsive force upon each other and undoubtedly consist of streams of neutral atoms.

The arc core appears as a narrow bright bluish band within these blasts of hot gases. Yet, it does not constitute an integral part of the

TABLE I

Test No.	1	2	3	4	5	6
Anode	Iron	Iron	Graphite	Graphite	Graphite	Iron
Cathode	Iron	Iron	Graphite	Graphite	Iron	Graphite
Polarity of the upper electrode	—	+	—	+	—	—
Total energy developed in the arc, in g-cal.	16,400	16,400	11,400	13,100	9,840	16,400
Energy measured at the anode, g-cal.	6,380	6,800	7,010	8,400	5,160	7,920
Energy measured at the cathode, g-cal.	7,000	6,430	3,140	3,760	4,250	5,330
Sum of anode and cathode energies, g-cal.	13,380	13,230	10,150	12,160	9,410	13,250
Losses by evaporation, radiation, etc., in per cent	18.4	19.3	11.0	7.2	4.4	19.3
Distribution of energy in per cent:						
Anode	38.9	41.4	61.5	64.1	52.4	48.2
Cathode	42.7	39.3	27.5	28.7	43.2	32.5

blasts, and, under certain conditions, (Fig. 8) may be pushed out of the envelope of hot gases. It could be observed, then, as a bright bluish band bridging the air space between the two blasts or jets of hot gases, tending, like a spring, to unite them. This tendency of the arc core to locate itself within the blast of hot gases is due to the greater ease of ionizing those gases than the air.

Table I also shows that in the case of an iron arc, the upper electrode, regardless of its polarity, receives more energy than the lower one. This is due to the influence of the ascending stream of hot gases. If the

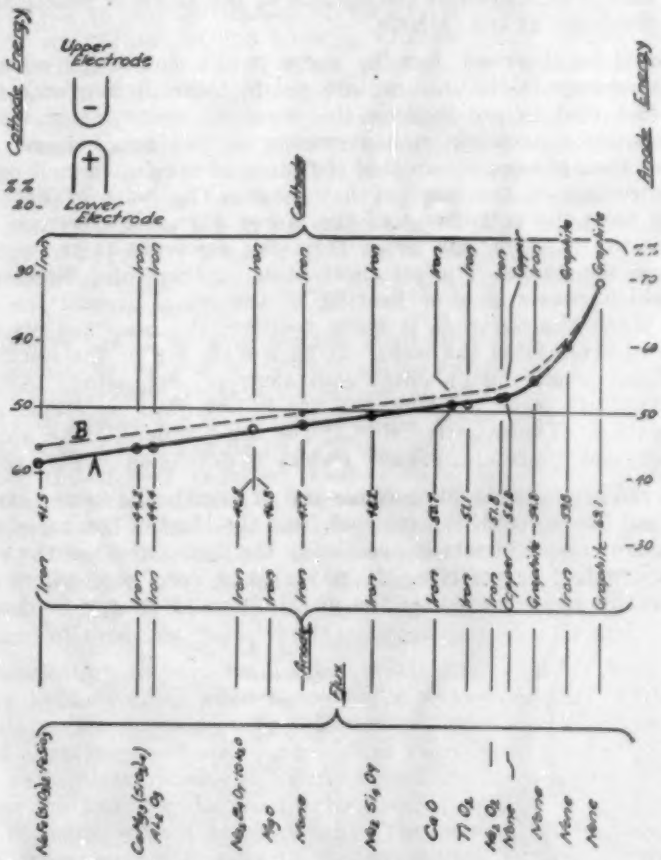

FIG. 9—CURVES SHOWING RATIO BETWEEN ANODE AND CATHODE ENERGIES FOR VARIOUS FLUXES AND ELECTRODES

necessary correction is made, the ratio between the energy developed by the arc at the anode and cathode of an iron arc is almost unity and can be expressed in per cent as 49.5 per cent for the anode and 50.5 per cent for the cathode.

The third series of experiments was conducted for the purpose of

determining the influence of various fluxes. Fig. 9 shows how various fluxes alter the distribution in the arc.

CONCLUSION

The experiments described above should be considered only as the first approach to the solution of the problem of the distribution of energy in the welding arc. It is realized that other factors, such as unequal heat capacity of the electrodes, radiations from the larger positive crater, etc., will have considerable bearing on the heat distribution between the electrodes. It may be concluded, however, that in an iron arc the energy developed at the surface of the anode is practically equal to that developed at the cathode.

It should be observed that the above results indicating equal distribution of energy in the iron arc are not in contradiction with the well-known fact that in arc welding the electrode melts faster when it is made positive. Accurate measurements of the arc voltage and the energy of the arc have shown that the cause of the faster melting resides in the direction of the blast of hot gases. The blast of hot gases is stronger from the cathode spot; therefore, when the electrode is made negative, the blast of hot gases from the electrode is more powerful than from the anode. The resultant blast is, therefore, directed downward, which causes greater heating of the metal around the positive crater. When the electrode is made positive, the resultant blast of hot gases is directed from the weld. It bathes the tip of the electrode like a hot flame, producing an effect equivalent to preheating. Also, when the electrode is made positive, the arc is not quite as stable as when it is negative. The negative side of the arc wanders. The arc voltage is greater, and, therefore, greater energy is developed in the arc.

When the arc is made quite stable and of exactly the same current and voltage and the electrode is protected from the blast of hot gases, the rate of melting of the electrode is practically the same, whether the electrode is made negative or positive. It may also be seen how different fluxes placed on the anode may alter the distribution of energy in the arc.

Design and Fabrication of Oxy-Acetylene Welded Buildings*

By H. M. Priest†

WELDING in the fabrication of structural steel has rapidly come to be an adjunct of the riveting process. For certain types of industrial and tier buildings it offers possibilities in the reduction of steel required, in the simplification of details and a more flexible adaptation of the steel to architectural requirements. Repairs or additions to existing structures can often be carried out most advantageously by employing the welding process. This field is constantly widening and today bridges are being reinforced to carry the increased locomotive loadings and extensions are being made to buildings in which welding is being used for joining the new steel to the old. The solutions of such problems offer real opportunities for the ingenuity and resourcefulness of designers.

The effective use of welding depends upon the designer having a clear idea of the process to be used, together with a knowledge of shop practice in structural fabricating plants. First, let us consider the oxy-acetylene process as it affects the work of designing structures. This concerns chiefly the type of weld and its location on the steel. A butt weld is most economical of the heat required because there are only two paths of steel through which radiation can take place. The same is true of fillet welds when located at the edges of the parts to be joined. Present practice more or less limits the butt weld to compression joints and uses the fillet weld for shear and tension in addition to compression. The more nearly the welding can be kept to these conditions the less will be the expenditure of time and gases in obtaining satisfactory results.

The fabrication of structural steel involves a series of steps which should be kept in mind when preparing a welded design. These steps or operations are carried on in different parts of the shop and are so arranged that the steel follows a logical path from its entrance until it leaves as a finished product. Briefly stated, the procedure is as follows: Templates, for locating the holes to be punched, are laid on the steel and marks are made with a prick punch. The steel is then taken to the punches, from whence it goes to the assembling skids. All the parts which are to be riveted together are collected at this point and temporarily bolted in place. The next step is that of riveting up the member and when this is completed the fabricated piece either goes to the shipping yard for painting or possibly to the milling machine for finishing. All of

*Read before the 30th annual convention, International Acetylene Association, Chicago, Ill., Nov. 13-14-15, 1929; also read before Joint Meeting of New York Section, A.W.S. & A.S.C.E., Nov. 20, 1929.

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these operations require handling of the piece at each point and between points. For heavy pieces this handling is a very considerable item of expense.

It is well to consider how welding affects the procedure just outlined. In the first place, it does away with riveting and consequently with the punching operation. However, a certain amount of punching will still be required to provide holes for bolting the members together in the field. One principle of economic fabrication follows quite obviously that punching of main material should be avoided and holes be kept in the small detail pieces. The latter can be handled much more readily and cheaply at the punches. In other words, once a saving of one or more

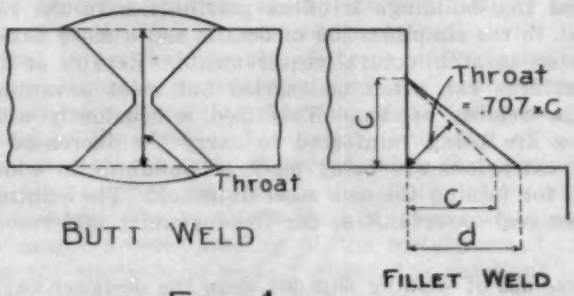


FIG. 1.

operations becomes possible, that saving should be utilized by proper arrangement of the details. Material in the shop should be segregated and as far as possible the number of different operations to be performed on each piece should be limited. With a reduction of punching there is a corresponding decrease in template work and an increase of work of laying out directly on the steel. Whenever there is sufficient duplication to warrant the expense, it is desirable to construct jigs for locating and holding the parts in their proper relation until welded. Clamps replace bolts in assembling and some thought should be given to reducing the number required.

It hardly seems necessary to emphasize the importance of locating welds and arranging the details so that the work is accessible. There should be enough room for the welder to manipulate his torch and welding wire and to secure good fusion at the root of the weld without interference from surrounding parts. It is also essential that he be able to see the work. Welds can be made in any position—horizontal, vertical or overhead, but the most economical positions are on planes between 0° and 45° with the horizontal. In the shop it is possible to turn the piece so that most welding can be done in a flat, downward position.

The foregoing considerations form a background for the more detailed study of the application of welding to structural steel. The starting point in the design of welded joints is the choice of unit stresses. In 1928 the American Welding Society approved and published a "Code for Fusion Welding and Gas Cutting in Building Construction." As stated

in the preface, "the various regulations are based on practices which have been demonstrated to be safe by experience." The permissible unit stresses which are recommended are as follows:

Shear on section through throat of weld = 11,300 lb. per sq. in.
Tension on section through throat of weld = 13,000 " " " "
Compression on section through throat of weld = 15,000 " " " "

Fig. 1 shows what are considered to be the throat dimensions for the butt and fillet welds.

When fillet welds are used it is more convenient for the designer to use

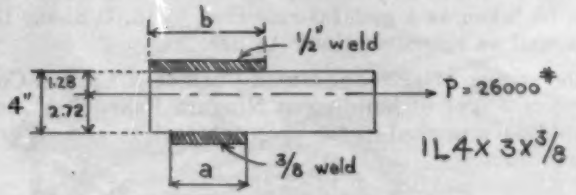


FIG. 2

a stress per linear inch, and Table No. 1 gives such stresses based on 11,300 lb. per sq. in. through the throat.

TABLE NO. 1

Size of Weld, Inches	Unit Stresses, Lb. per Lin. Inch
1/4	2,000
3/8	3,000
1/2	4,000
5/8	5,000
3/4	6,000
7/8	7,000
1	8,000

Symmetry is a desirable feature for both the structural member and the disposition of the welding. It is not always practical or economical to use symmetrical sections and in such cases allowance must be made for eccentricity. The method of dealing with eccentricity can be illustrated by designing a simple joint for an angle which is the most common unsymmetrical section. Fig. 2 gives the assumptions and the solutions, which are based on the principle of mechanics that the moment of the forces on either side of the center of gravity shall be equal.

Let "a" and "b" be the unknown lengths of welding to be determined.

(1) $3000\ a + 4000\ b = 26{,}000$
(2) $3000\ a \times 2.72 = 4000\ b \times 1.28$

From equation (2)

$3000\ a = 1880\ b$

Substituting this value in equation (1) $1880\ b + 4000\ b = 26{,}000$

$b = 4.43$
$a = 2.77$

Allowing ½ in. for the beginning and end of each weld, the specified lengths would be a = 3¼ in. and b 5 in.

It is well to remember that an angle also has an eccentricity about an axis parallel to the leg that is welded and for this reason it is better to use angles with unequal legs and weld the longer one in order to reduce the eccentricity. When a single angle is used, the allowable unit stress on the angle should be taken as 6/10 of the usual working stress.

The size of fillet weld to be used depends upon the thickness of the parts being joined. Based upon investigations of the Linde Air Products Company, it has been shown that the sizes given in Table No. 2 offer a balanced heat condition for maximum rate of welding and can be used as a guide in the selection of the proper size for any given problem. Unless the size is limited by the thickness of the material on the welded edge, it can be taken as a general rule that ½ in. is about the minimum practical as well as economical size to use.

During the spring of 1929 the Union Carbide & Carbon Company built a steel frame mill type of building at Niagara Falls, N. Y., in which oxy-acetylene welding was used in the shop fabrication and on erection. The

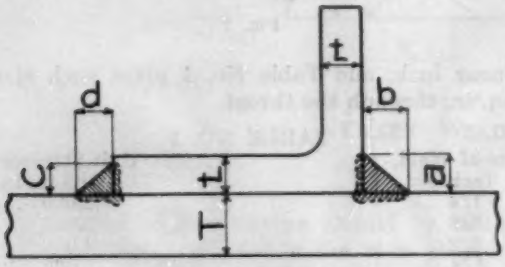


TABLE No. 2

DIMENSIONS OF WELDS

T	t	a	b	c	d
3/8	1/4	1/2	1/2-5/8	1/4	3/8
1/2+	3/8	1/2	5/8±	3/8	1/2
1/2-3/4	1/2	1/2 5/8	5/8± 3/4±	1/2	5/8
5/8-1	5/8	1/2 5/8	5/8± 3/4±	1/2	5/8
3/4-1 1/4	3/4	5/8 3/4	3/4± 7/8±	1/2 5/8	5/8 3/4

treatment of a few of the problems arising in the design of this structure will illustrate some of the principles mentioned above. Fig. 3 is a general view of the completed frame which offered a wide variety of points to be studied.

The truss was of the Fink type, modified slightly to bring each half within the shipping limits. The detail at the heel is shown in Fig. 4. It will be seen that the chords are made up of halves of C B beams with the stems butt-welded at their junction. The stress in the flange of the

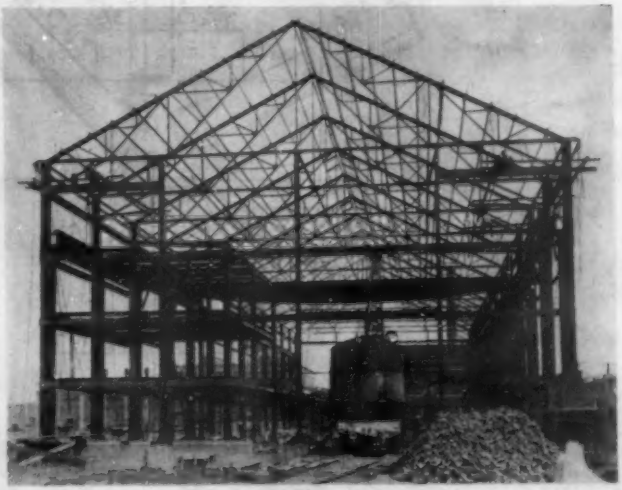


FIG. 3

top chord was transferred through two bars 3 x ¾ butt-welded to the end of the flange and welded to the stem and flange of the bottom chord. Bars were added to either side of the web to prevent any tendency for it to buckle. A bearing plate with holes for bolting the truss to the column cap plate was shop-welded to the bottom flange.

Fig. 5 indicates the method of handling the field splice at the peak of the truss. While the truss was still in the jig at the shop the pair of angles 3 x 3 x ⅜ were bolted together and each one welded to a half of the truss. When the half trusses were assembled in the field these two angles brought the ends of the top chord into proper position and alignment and held them in place until the welding was completed. The square cut ends of the top flanges formed a natural vee for butt welding. The center vertical, together with the clip angles, was an ample splice for the stems.

A typical joint as given in Fig. 6 brings out one principle of design, namely, that the center of gravity lines of the various members should meet at a point. Slight deviations from this rule can be made if judgment is exercised in laying out a joint, but in general the rule should be observed.

The bottom chord splice is shown in Fig. 7. The center section had no shop welding on it so it was decided to put the holes for the field assembly bolts in this member. The corresponding holes on the half trusses were located in detail pieces; that is, in the bracing gusset plates. A little study of Figs. 4 to 7 will bring out the fact that no holes were punched in top and bottom chord sections, except for the center section, and that

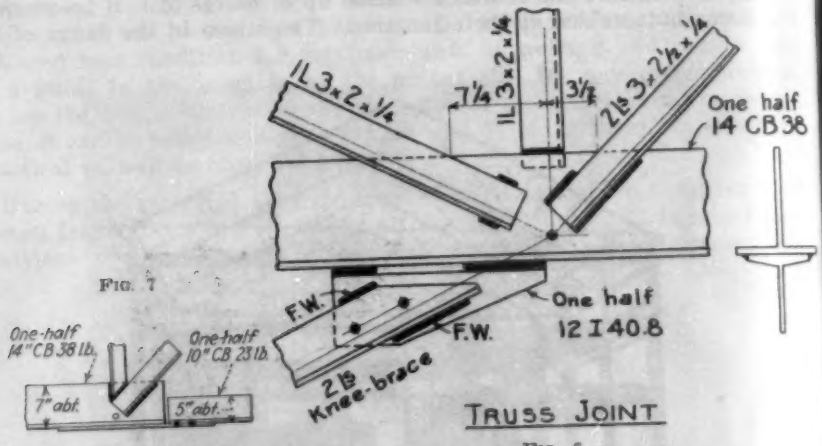


FIG. 7

TRUSS JOINT

FIG. 6

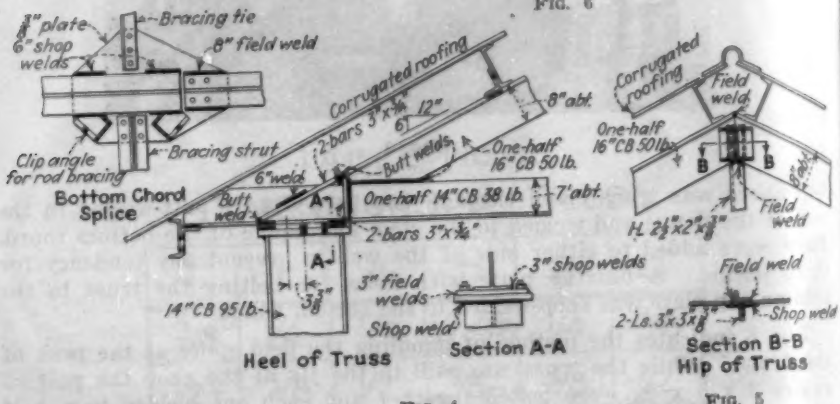


FIG. 4

FIG. 5

such holes as were required for erection were all located in plates or clip angles welded to these members. Furthermore, the welding was kept at or near the edges of the material wherever possible so as to reduce the heat radiation.

The splice for the crane columns is illustrated in Fig. 8. The welding was calculated to develop the bending moment of the 14 C B 95 at 16,000 lb. per sq. in. ⅝ in. welds were used except where the splice plate was welded to the web of the 24 C B 100 in the lower section of the column. A ⅜ in. weld was called for at this point in order to get a longer weld and so reduce the shear on the web to safe working limits. All welding

on the splice was kept 1½ in. from the finished edges in order to avoid heating the milled surfaces to welding temperatures.

A wide flanged beam was selected for the crane girder instead of the common type of beam with side channel. It was decided that the extra weight required by the single beam more than offset the extra expense which would have been incurred by assembling and welding the channel and beam. No punching was done on the crane girder beam, thus doing away with extra handling of a heavy member. The few holes for field erection were all put in detail pieces, which were welded to the beam.

Anchorage of the columns to the foundations was accomplished through a simple and effective detail, using short lengths of pipe welded to the edges of the column flanges. Fig. 9 is a sketch of the method used on

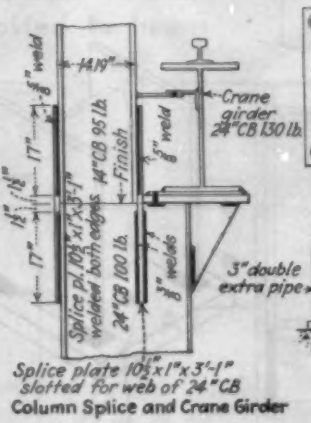

14½"
Crane girder 24"CB 130 lb.
24"CB 100 lb.
Splice pl. 10½"x1"x3'-1" welded both edges 14"CB 95 lb. Finish
24"CB 100 lb.
3" double extra pipe
Shop weld
Splice plate 10½"x1"x3'-1" slotted for web of 24"CB
Column Splice and Crane Girder

FIG. 8

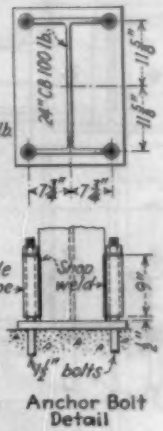


FIG. 9

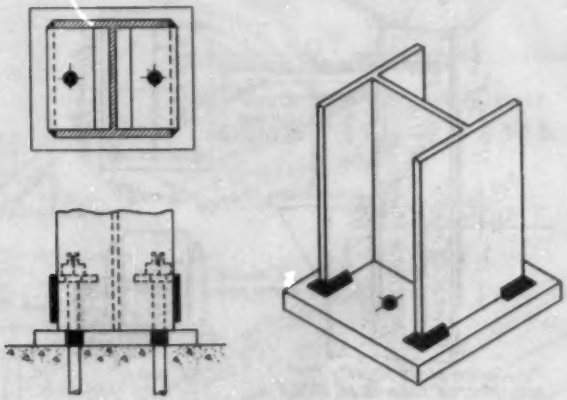
the crane columns which were designed for a point of contraflexure 1/3 of the way up the column. This produced an uplift of 63,000 lb. on each pair of bolts which had to be taken into account. The Linde Air Products Company had tests made at Columbia University on this type of connection, which indicated that the design was amply strong. In this investigation two pieces of pipe 9 in. long and welded for 3 in. at the top and 3 in. at the bottom carried a load of 213,000 lb. at the drop of the scale beam and were carrying 303,000 lb. when another part of the apparatus failed.

In Fig. 10 are given two methods of anchoring columns to the foundations. The base plate for the left-hand sketch is shipped loose, while the right-hand sketch has the plate welded directly to the column. Here again it will be noted that the welding is disposed along the edges of the material and while this arrangement is advantageous as regards heat radiation, it also puts the welds in very effective locations from a design point of view.

Various methods of beam framing suggest themselves and a few

examples are shown in Figs. 11 and 12. Erection is facilitated if the connections of beams to columns are temporarily bolted so as to hold the structure in place and to permit adjustments in plumbing the columns. The 12 in. C B 25 lb. beams in Fig. 12 were shipped directly to the site from the rolling mill, as there was no shop work to be performed on them.

One important point in the locating of welds is that of making provision against the handling and shipping knocks to which the piece will be subjected. These often become the chief consideration instead of the actual stress which may have to be carried. For example, in Fig. 10 the welds could be placed at the center of the column flanges and be ample to transmit any stress or load that might come on them but be ineffec-



COLUMN BASES

FIG. 10

tive in resisting a blow on one corner of the base plate. When the welds are on the corners of the flanges they are far better placed to take the shocks of handling.

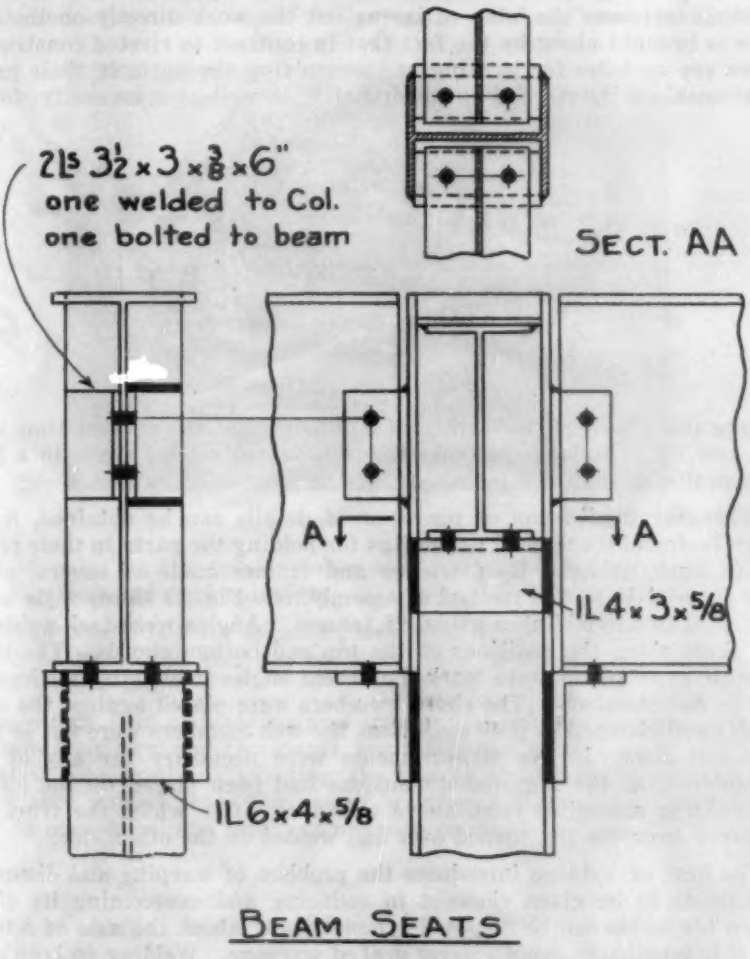
Welding operations in the shop should be conducted under proper procedure control, with qualified welders and competent inspection. As the success of welding, from the standpoint of weld quality, largely depends upon the skill and ability of the welder, it is essential that his work be checked and tested. In laying out a program for testing a variety of welded joints, the Structural Steel Welding Committee of the American Welding Society prepared specifications covering the qualification of welders. While these specifications are intended to apply to this investigation only, they afford a reliable method for examining any operator.

The tests are divided into three parts as follows:

(a) Two 6 x ½ x 12 in. plates are butt welded together along the 12 in. edges, which have been machined to form a single V. The specimen is

then cut into coupons 2 in. wide, which are placed in a vise so that the top of the jaws grip the center of the weld longitudinally. By the use of a sledge these coupons are bent at the weld until fracture occurs.

(b) Fillet welds are made on the ends of plates and then broken open by driving a wedge between the plates at the opposite end from the welds.



BEAM SEATS

FIG. 11

In both tests "a" and "b" an inspection is made of the penetration, fusion between weld and parent metal, and the character of the fracture.

(c) Five specimens are required—three to be welded in a flat position and two in a vertical position. Each specimen is made up of 9 x ½ x 12 plates butt welded as in test "a." Four standard A. S. T. M. coupons are cut and machined from each specimen. These coupons are given a

tensile test and the average strength required for gas welded specimens shall not be less than 52,000 lb. per sq. in., with no coupon showing less than 50,000 lb. per sq. in.

"The methods of handling welded work vary with the individual shops, but a few general observations are applicable to any welding operation. As was pointed out under considerations affecting the design, the use of welding increases the labor of laying out the work directly on the steel. This is brought about by the fact that in contrast to riveted construction there are no holes for locating and assembling the parts in their proper relationship. Herein lies an opportunity, as well as a necessity, for re-

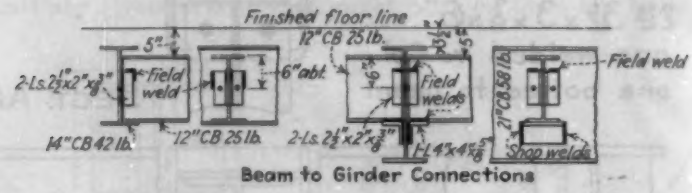


FIG. 12

ducing this phase of the work to a minimum. At the present time welding and its attendant shop operations have not settled down to a basis comparable to that of riveting.

Whenever duplication of pieces or of details can be obtained, it will often be found economical to use jigs for holding the parts in their proper places until welded. Roof trusses and frames made of several pieces lend themselves to this method of assembling. Fig. 13 shows a jig which was used in assembling a group of trusses. Angles were tack-welded to the skids along the positions of the top and bottom chords. The intermediate panel points were marked on these angles to simplify the locating of the web members. The chord members were placed against the angle guides and clamped in position. Next the web members were put in position and clamped. No measurements were necessary for any of this assembling, as the required dimensions had been placed on the guides. All welding accessible from above was done, after which the truss was removed from the jig, turned over and welded on the other side.

The heat of welding introduces the problem of warping and distortion and needs to be given thought in reducing and overcoming its effect. When the welds can be disposed symmetrically about the axis of a member it is possible to avoid a great deal of warpage. Welding on both sides of a detail simultaneously will materially reduce if not eliminate the trouble. In some cases it may be found that reversed bending or leaving an unequal gap between pieces before welding will bring the pieces into proper alignment after welding. Truss members, for example, will remain sufficiently straight for practical purposes if they are securely clamped and tack-welded. A little study or experimenting in the shop will quickly develop satisfactory methods for dealing with warping whenever it occurs.

The Code for Fusion Welding and Gas Cutting in Building Construction contains the following clause in regard to painting:

"Structural steel parts shall not be painted before they are welded. Parts that are welded in the shop, to be erected by bolts or rivets, shall receive the usual painting after the shop welding is finished. Parts to be field welded shall receive a coat of linseed oil after shop work is completed, and after erection and field welding, they shall receive as many

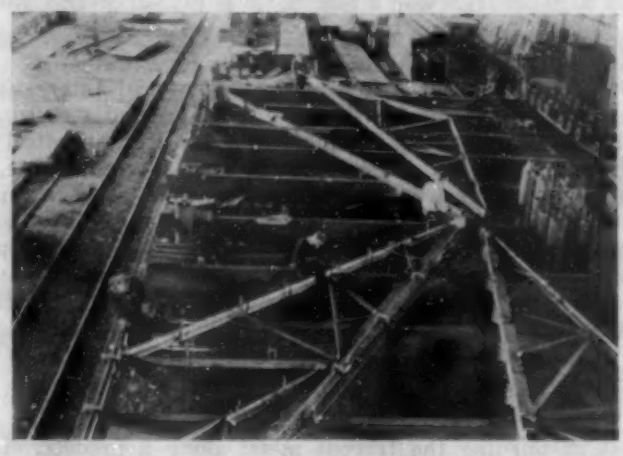


FIG. 13

coats of paint as the total number specified elsewhere in the Building Code for shop and field painting."

This provision is made because paint tends to interfere with the sound quality of welds and also welding over paint produces fumes which the welder cannot avoid.

The whole field of welding and its application to structural steel is comparatively new and this paper has attempted only to point out some essential considerations affecting the use of the oxy-acetylene process. Experience gained from the use of welding will gradually build up a body of economical and practical methods on which to base a design.

Cutting Steel Shapes with Oxyacetylene Torch Machines*

F. E. ROGERS†

DURING the past few years general industrial interest has been aroused in the use of fabricated steel plates and structural shapes for welded assemblies to replace equivalent gray iron and steel castings. Machine bases, sub-bases, frames, housings, tables, uprights, spiders, rotors and gear blanks are examples that lend themselves to this method of construction. Advantages of fabricated welded steel are: less weight, reduced cost and little liability of breakage in use and in transportation. The elimination of pattern making and the time required for making castings are also important. But without taking space to discuss these advantages in detail, we will pass on to a discussion of an economical method of shaping steel to the great variety of sizes and forms required, namely, oxygen cutting.

Oxygen Cutting: Oxygen cutting of steel, wrought iron and cast iron is a process of burning the ferrous metal along a predetermined path with a stream or jet of oxygen when the metal has been preheated at the starting point to a bright red. Only the red-hot metal in the path of the oxygen jet burns while the cooler metal immediately adjacent is unburned and practically unaffected beyond narrow zones, usually less than 1/16 in. thick each side the cut.

Heating for cutting is accomplished with a small flame or flames close to a central orifice in the torch tip through which the oxygen cutting stream issues. The number of these heating flames varies from one to six—seldom more. One flame is rarely or never used, and seldom are more than four or five required with the high temperature fuel gas acetylene, except when cutting cast iron. Four or five preheating flames assure one or two flames always being ahead of the oxygen jet when cutting in any direction in a plane parallel to the surface of the piece cut.

Oxyacetylene Cutting: As intimated in the foregoing, the fuel gas for the preheating flames that gives the most general satisfaction, considering time required for starting the cut and oxygen consumption, is acetylene. Hence, we shall refer hereafter to cutting performed with acetylene preheat as oxyacetylene cutting.

Inasmuch as cutting or burning to effect separation is confined to a narrow kerf slightly wider than the diameter of the oxygen jet, throughout the depth of the cut, even if 12 in. or more, it is apparent that

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*Paper presented at joint meeting of American Welding Society and American Society of Mechanical Engineers, New York, Jan. 7, 1930.

†Applied Engineering Department, Air Reduction Sales Co., New York.

gas cutting can be compared to metal sawing, the "saw" being a stream of oxygen instead of a steel blade or disk.

Oxyacetlyene cutting was practiced at first with hand torches exclusively, and the hand torch is still the principal gas cutting tool. The operator holds the torch at the required height from the surface and follows the line of cut. He must move the torch steadily in step with the cutting action. If moved along the cut much faster or slower than the cutting action, the cut is "lost" and a new start must be made.

Thus, as with other hand operations the accuracy, smoothness and efficiency of cutting depend upon the skill and care of the operator. The thicker the metal, the more difficult is hand cutting, owing to the slow rate of progression compared to most hand movements, and the necessity of

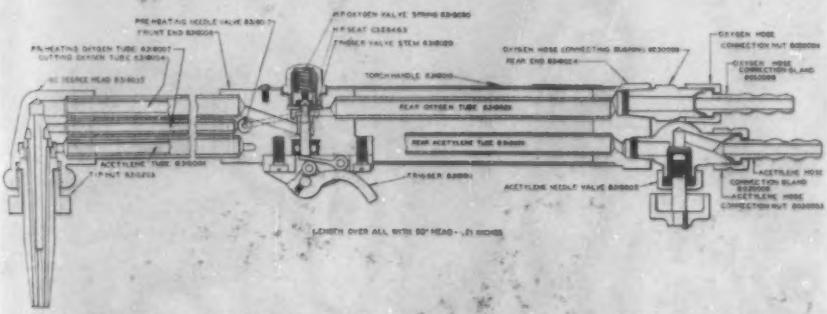


FIG. 1—HAND CUTTING TORCH IN SECTION, SHOWING FINGER CONTROL OF CUTTING OXYGEN VALVE

holding the torch so that the cutting jet shall be projected squarely through the piece. Slight variations in the side angle at which the torch is held, and variations in speed that might have little noticeable effect on thin plates, are likely to produce shape defects when cutting thick plates, slabs and forgings. The shape cut is likely to have one form at the top surface and another at the bottom.

Efficiency in the foregoing refers to consumption of oxygen and acetylene as well as cutting time. The volume of oxygen used is almost directly proportional to the volume of steel oxidized and displaced in the cut. The wider the kerf, the greater the weight of steel burned away, and the larger the volume of oxygen used. The hand torch operator cuts a wider kerf than a machine torch because the torch in his hands wavers slightly from side to side, and the cutting jet thus covers a wider area.

These limitations of hand cutting were recognized years ago, and one of the first efforts to improve the characteristics of the cutting torch was the application of two small wheels on an axle to support the torch at the proper height and side angle. The axle was provided with means for clamping the cutting tip to the axle at the height required for cutting. Thus equipped, the torch can be pushed or pulled along with the assurance that the tip will be held constantly at the correct side angle and height from the surface. This device, never very popular in this country, is used abroad, especially in shipyards when making cuts in large plates.

Straight Line Cutting Machines: Straight line cutting machines were developed early in the present century shortly after the invention of the oxyacetylene welding torch. The first cutting torch, a simple adaptation of the welding torch to convert it into a cutting tool, had an auxiliary oxygen tube clamped at the side. This tube supplied the oxygen cutting jet, and the welding flame (reduced) was used for the preheat.

The straight line cutting machine comprised a vertical frame with supports, a horizontal slide way or track, a slide closely fitting the track,

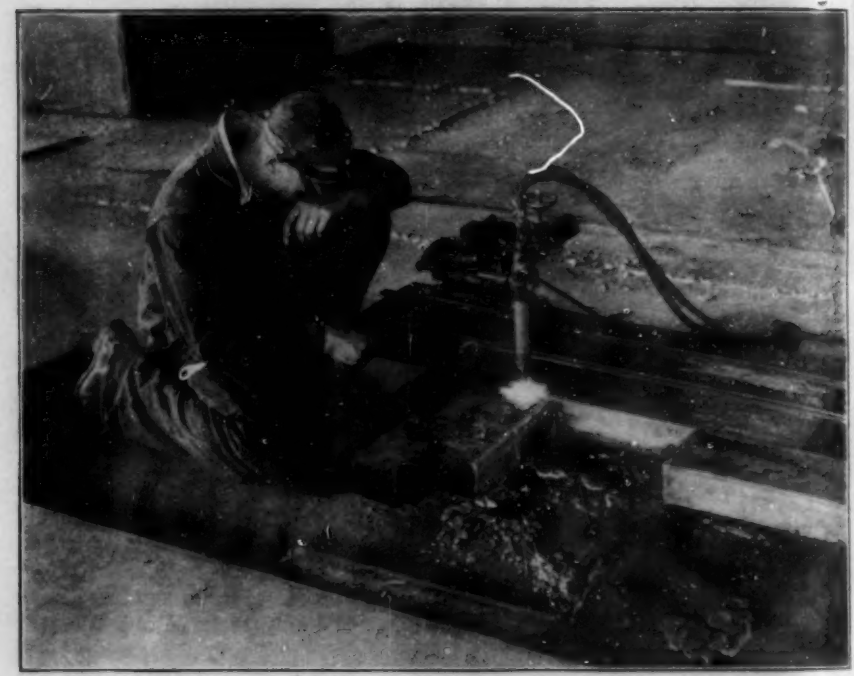


FIG. 2—RADIAGRAPH FOR AUTOMATIC CUTTING OF STRAIGHT LINES AND CIRCLES. IT IS SHOWN CUTTING THROUGH 4-IN. METAL

a cutting torch (usually a torch with a straight head), adjustably fixed to the slide, a horizontal screw engaging the slide, and handwheels or cranks mounted on the ends of the screw, to operate.

The slide is thus propelled across the work members, and the torch carried at the height and angle to make the desired cut. If a bevel cut is desired, the torch is adjusted to the angle the same as a planer head tool is set when planing an angular surface, or, a bent tip is employed that projects the cutting jet at the required angle.

A hand-driven cutting machine requires the constant attention of the operator, and under some conditions of operation it is difficult to turn the crank at a constant speed and give the necessary attention to the torch. Also, the cutting speed varies from, say, 3 in. per minute on heavy work to 25 in. or more per minute on thin plates.

The requirement of a fairly constant rate at any speed within the variable speed range mentioned, of course, is beyond realization with hand operation, and the next logical step was the application of motor drive, using a constant speed motor and change gears, or a variable speed motor to propel the torch.

Self-Propelled Cutting Machines: Cutting machines, motor-driven, are in three general classes as regards relation to the work, that is, portable,

FIG. 3—RADIAGRAPH CUTTING CIRCULAR SHAPES IN 3-IN. STEEL

semi-portable, and stationary. In shipyards, bridge works, and industrial plants where large tonnage of steel plates is handled daily that requires trimming, splitting, beveling and cutting to length, portability is important. It is desirable to take the machine to the work rather than transport the work to the machine. Labor and crane service are reduced in due proportion to the reduction of handling.

The Radiagraph: This machine, weighing about 120 lb., carries a straight head machine torch with means for setting the torch at any angle required for beveling or cutting a calking edge. A compound slide rest provides for vertical and horizontal adjustments also.

The carriage is on three small wheels, two being tractors and the third, a free wheel. When cutting to straight lines, the wheels run on a grooved track, and when cutting to circular arcs or circles, the machine revolves around a pivot point fixed to a radius rod. Only one of the tractor

wheels then is used to drive, and the free wheel which is mounted like a caster follows the path set by the radius bar.

This machine is useful for fabricating shapes from steel plates or slabs —squares, rectangles, strips or any shape bounded by straight lines; or

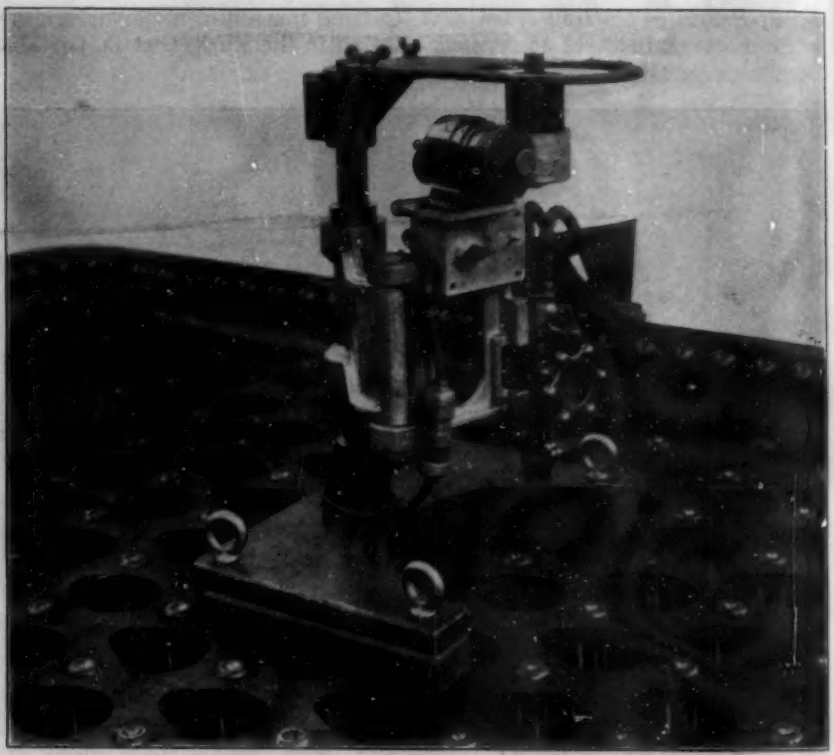


FIG. 4—CAMOGRAPH SET UP IN BOILER FOR CUTTING HANDHOLES IN A WATER TUBE BOILER HEADER. A LIGHT CAGE WITH FOUR HOOKS IS USED IN THIS PLANT TO LIFT AND CARRY THE CAMOGRAPH ABOUT THE BOILER SHOP. SHIFTS FROM ONE HOLE TO NEXT ARE MADE BY HAND. THE MACHINE WEIGHS 180 POUNDS COMPLETE

circles, rings, flanges, and shapes bounded by straight lines and circular arcs.

Fabrication of a three-throw crankshaft from a plain steel slab by combination of cutting, twisting and forging is one only of many operations in which gas cutting can be used to advantage in the forge shop.

The Camograph: The machine just shown is portable and is guided by a track or a radius bar. The present machine is semi-portable, weighing about 150 lb., and can be taken to the job, or when the parts are easily handled it may be used to advantage in a stationary position.

Unusual and interesting means are employed for guiding the cutting torch. The torch is mounted on a vertical slide at the outer end of a double hinged arm. The hinged arm is supported by a vertical post fixed

in a U-shaped base. At the top of the post is a cam holder designed to hold in horizontal position an internal cam, that is, a plate having an opening, the shape of which is approximately the shape to be cut. Contacting with this inner surface is a magnetic roller driven by a variable

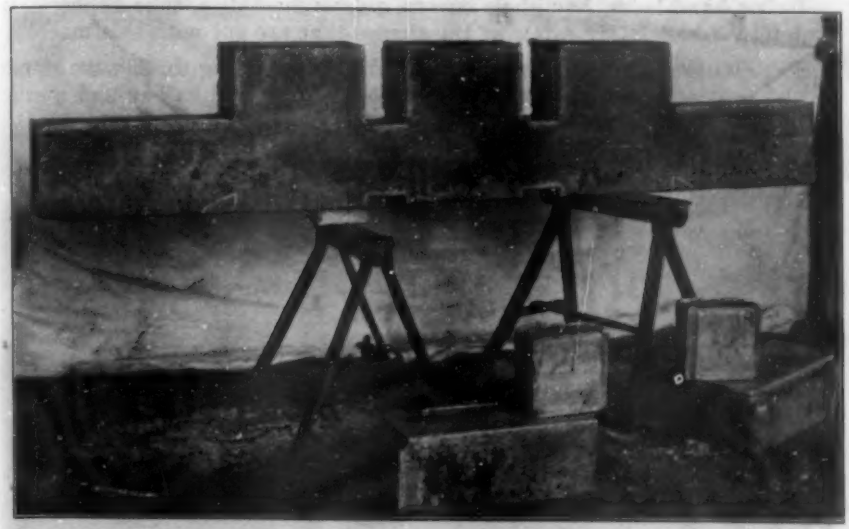


FIG. 5—THREE-THROW DIESEL ENGINE CRANKSHAFT FORGED WITH AID OF RADIAGRAPH CUTTING

FIG. 6—FORGING FOR DIESEL ENGINE CRANKSHAFT BLOCKED OUT BY RADIAGRAPH CUTS FOR FORGING OPERATION OF ROUNDING UP BEARINGS AND TWISTING

speed motor. As the magnetic roller turns on its axis it follows the cam shape and carries the straight head torch with it, cutting the shape below. Only one shape can be cut with a given cam. Hence, this is a repetitive production cutting machine.

Boiler hand-holes, hand-hole covers, rubber heel dies, tube supports in water tube boilers are a few of the shapes that are cut with this machine.

The Oxygraph: Three means for guiding the cutting torch were shown in the previous two machines—a straight track, a radius bar and a cam.

The machine shown in Fig. 11 is primarily hand-guided, although it can be adapted to templet, radius bar or cam control, if desired. A square

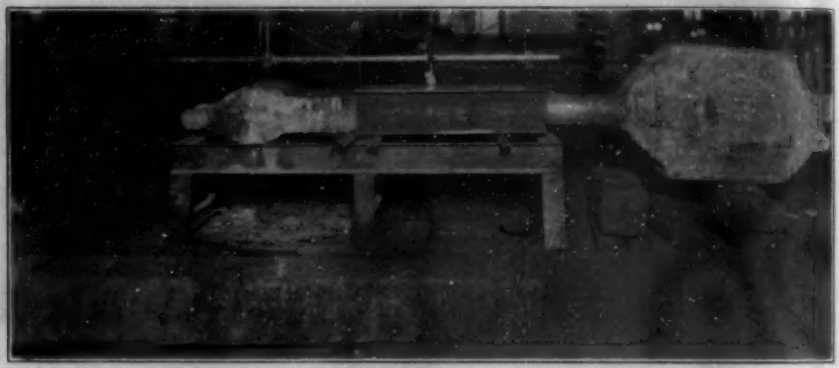


FIG. 7—CUTTING THE FORKED WRIST-PIN END OF DIESEL ENGINE CONNECTING ROD WITH OXYGRAPH. NOTE THAT THE THICKNESS VARIES FROM 12 TO 16 INCHES IN THE THICKEST PART AND DOWN TO ABOUT 6 INCHES AT THE END

bar in front mounted on a pantograph assembly carries a torch or torches, and a tractor device, motor-driven that is steered by the hand twisting the vertical sleeve above the tractor or tracing wheel. The tracing wheel can be made to follow the lines of a drawing laid on the table, and the outline cut with the torch. If two or more torches are fixed to the bar, two or more duplicate shapes are cut simultaneously.

Multiple Cutting: This machine is capable of multiple cutting of shapes, using two or more torches on one thickness of steel plate, or cutting in multiple from a stack of two or more plates with one torch, or of cutting shapes from a stack of two or more plates with two or more torches. Multiple cutting of plates in stack is being practiced to advantage as for instance in airplane plants for cutting small shapes from thin steel plates used in welded fuselage assemblies, twelve or more shapes being cut at once with one torch.

Thin plates must be clamped to hold them from buckling with the heat. In some cases a thicker plate on top is used as a clamping member to hold the plates beneath and to absorb some of the top heat.

Multiple cutting of steel plates from 1/16 in. to ¾ in. thickness or more is employed in airplane plants, car shops, industrial plants and where many pieces of the same shape or shapes are used in repairs and pro-

duction. An example of a large part cut in multiple is a section of Pullman car vestible frame.

The conditions that must be met in multiple cutting are more exacting than with single piece of thickness equal to the height of the stack. A machine flexible in operation not rigidly held to starting at a particular spot is necessary for the best results. However, the portable motor-driven machine briefly described is used for cutting pipe flanges or large

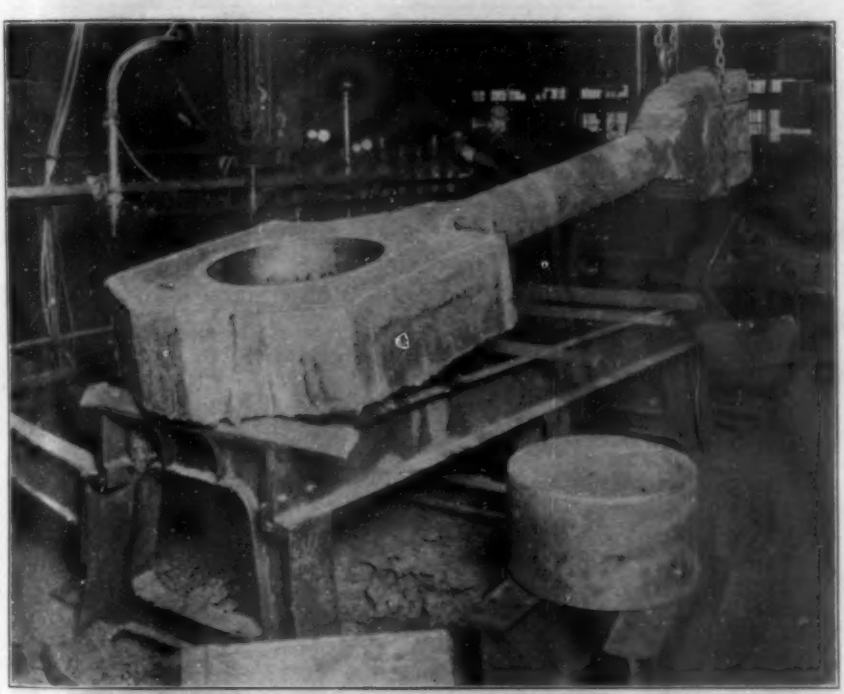


FIG. 8—THE STEEL OF THE CONNECTING ROD WAS 12 INCHES THICK AND THE 22 INCH HOLE WAS CLEARLY CUT AT A RATE OF 3½ INCHES PER MINUTE. ON THIS WORK THE OXYGRAPH SAVED APPROXIMATELY $160 PER CONNECTING ROD

diameter holes in steel plates ¼ in. up, stacked to a height of six in. or more.

Economy: Oxy-acetylene cutting of shapes requires little power for machine operation. No costly tools, dies or shear blades are necessary. Several duplicate shapes can be cut at once under favorable conditions. Cutting can be done with such smoothness and accuracy that the parts may be used for many purposes with no machine finish.

A 10-in. circle is cut smoothly from ¾-in. low-carbon steel in two or three minutes at a cost of about 20 cents, computing oxygen at $1.25 per 100 cu. ft., acetylene at $2.50 per 100 cu. ft. and operator's wages at 80 cents per hour. A 10-in. circle in 2-in. steel will cost more, of course, because the cutting is slower and more gases are used.

Many examples could be cited that would show machine cutting cost to be extremely low when compared to the costs of producing the same shapes with machine tools in the common ways. Costs of cutting the same shape vary, depending on the thickness and quality of cut required. A slower cutting speed must be used on heavy sections, especially if a smooth surface with minimum drag is required. Hence, a direct statement of cutting costs cannot be made without knowing the quality of steel, thickness, permissible drag and smoothness of cut desired.

If the most economical cuts are wanted, the speed is set at the highest

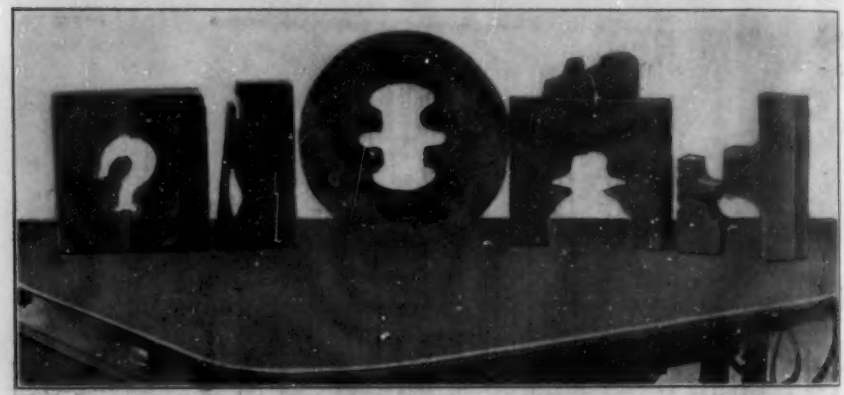


FIG. 9—DIES AND FORGINGS CUT FROM HIGH CARBON STEEL ON OXYGRAPH

FIG. 10—NAVY MAST BAND AND FORGING FROM WHICH IT WAS CUT WITH OXYGRAPH

rate that can be maintained without interruption. The drag may then result in some deformation of the lower side shape when compared with the top shape. This will be especially noticeable on shapes in which the direction of cut changes suddenly. If the cut shapes are to be used without subsequent finishing, then the cutting speed should be reduced

so the drag is not more than, say, 1/10 in. on ½ in. to ¼ in. on 2-in. thicknesses. This means that the curved line representing the cut markings should not fall behind the vertical at the top more than the given figures when smooth finish is wanted.

A common empirical rule for measuring the efficiency of oxygen consumed is to compare the number of cubic feet used with the area of cut

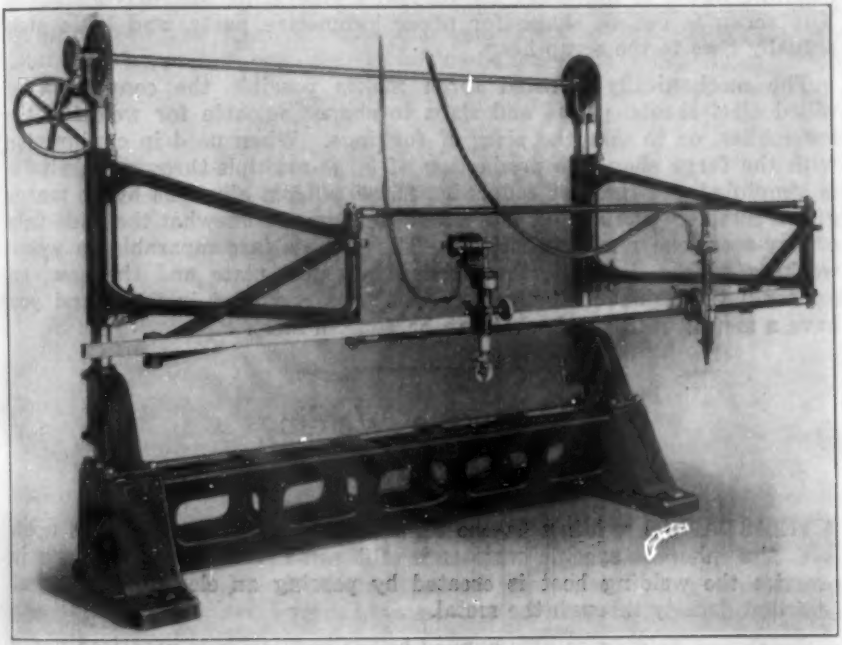


FIG. 11—OXYGRAPH SHOWING TORCH AND TRACTOR DEVICE ON HORIZONTAL BAR IN FRONT

surface, measured on one side of the kerf only. Economical machine cutting ½-in. plate is realized when 8 sq. in. of cut surface are produced by 1 cu. ft. This means that 16 in. of ½-in. plate are cut. If the thickness were 4 in., the factor becomes about 5; that is, about a 1¼-in. cut would be made in 4-in. steel with 1 cu. ft.

Effect of Cutting on Steel: What effect has this burning process on the steel next to the cut? Low-carbon steel used for ship plates, machine bases, structural shapes and the great mass of steel applications may be cut with no fear of detrimental effects. Steel containing much more than 0.30 per cent carbon should, as a rule, be warm when cut and annealed after cutting when employed for machinery parts, or a liberal machine allowance should be made to insure that the steel affected by the local heat will be removed. Contrary to general impression, this heat effect is chiefly mechanical. The grain structure is practically unchanged beyond a narrow zone, usually less than 1/16 in. thick, unless it be in a very thick section. The mechanical effect is a state of tension in the

surface layers of the cut surfaces, due to local heating and upsetting the metal as the cut is being made. Annealing relieves the tension and machining removes the metal affected.

Conclusions: Fabrication of shapes from rolled steel has almost unlimited possibilities and great economic advantages. Two concerns building mine locomotives have for several years cut their side frames from rolled slabs. Cutting is done so smoothly and accurately that no machine finish is necessary on the jaws embracing the driving boxes. The scrap is cut to shape for other locomotive parts, and little steel actually goes to the scrap heap.

The mechanically-operated torch makes possible the conversion of rolled steel sheets, plates and slabs to shapes suitable for welding into assemblies, or to take the place of forgings. When used in conjunction with the forge shop, the production of large multiple-throw crankshafts is simplified and the cost reduced. These random allusions by no means give a complete picture but may serve to suggest somewhat the wide field of oxy-acetylene machine cutting. The process is comparable to wood-working with a jig saw, the wood being steel plate and the saw, an oxygen jet. Think of the variety of forms produced in wood and you have a mental picture of what can be done in steel.

Resistance Welding

By Byron T. Mottinger[1]

RESISTANCE welding, as the term resistance implies, depends upon the inherent specific resistance of the metal to be welded, and in practice the welding heat is created by passing an electric current of sufficient density through the metal.

Resistance welding as now applied to the industries is practised under three general heads, as follows: (1) butt welding, (2) spot welding, and (3) seam welding.

There are some instances of resistance welding practised that lie in rather intermediate points between two or more of the above classifications, and such cases are not always easy to classify. However, in general, the three kinds of resistance welding are quite distinct forms, and no difficulty is experienced in classifying them.

I. Butt Welding

Butt welds are made between two pieces of metal held in dies as shown in Fig. 1. Butt welding comes under two classifications. The older type is known as a "straight butt weld," or frequently called a "resistance butt weld." It is produced by clamping the pieces to be welded between the dies, forcing the pieces together with some pressure, and then applying the welding current. The area of contact, at this stage, is naturally

[1] The General Welder Company, Akron, Ohio.

Presented at the Winter Convention of the A.I.E.E., New York, N. Y., Jan. 27-31, 1930.

quite restricted, and the small area is soon heated, which flattens down under the pressure and permits other areas to come into contact, and likewise become heated. As the hot metal has a very much greater resistance than the cold metal, there is a dispersing factor introduced which tends to equalize the temperature over the entire surface of the area of contact. The current is applied sufficiently long to permit the joint to become heated to the plastic state, at which time the two pieces are forced together vigorously, and an upset is produced as shown in Fig. 1. This type of weld depends upon the inherent resistance of the metal being welded and likewise upon the resistance of the contact at the joint, and hence has been termed a "resistance butt weld," in order to

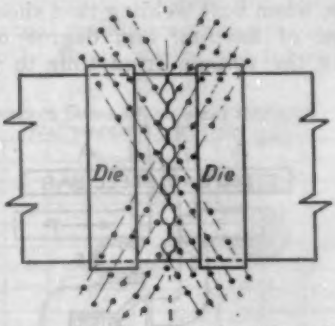


FIG. 1—APPEARANCE OF FLASHING ACTION IN BUTT WELDING

differentiate between it and the type of weld shown which is generally spoken of as a "flash butt weld."

The difference between the flash butt weld and the resistance butt weld lies in the fact that in the latter the welding potential is applied to the pieces before they are permitted to come into contact. Immediately upon making contact there is a violent arcing or sparking between the pieces, volatilizing and throwing out the metal about the contacting areas. This action, called "flashing," continues as long as the pieces are made to approach, one toward the other. The violence of the flashing increases with the increase in the speed of approach, assuming that there is sufficient energy to cope with the demand. The flashing period covers two distinct stages. The first stage is usually accomplished under uniform speed of approach, and continues till complete normalcy of areas is secured between the opposing ends to be welded. As soon as uniform flashing over the entire area is secured, then acceleration of the parts becomes necessary. The acceleration causes more metal to be volatilized and thrown out, and this in turn, increases the temperature of the ends to be welded. The acceleration plays another very important part. It prevents the heat running back toward the welding dies, and into the unheated sections, which in turn governs the nature of the upset upon completion of the weld. The steps, then, in making a flash butt weld are as follows: Clamp the pieces under the dies, apply the welding electromotive force, cause the pieces to approach at uniform speed until normalcy of areas is secured by flashing, then accelerate the speed of the approaching pieces

up to such a point where white heat and plasticity are assured, finish with a quick short upsetting blow. This process will insure the very best type of weld possible to secure, having a strength equal to the original metal and the very least possible upset. This covers the two essential requirements of all commercial mass production welds.

Up to the present time there has not been devised any scientific means for determining exactly what is happening in the flashing zone. From observation it appears that for a given speed of approach of the metals to the flashing zone, the higher the welding e. m. f. is held, the larger will be the flashing particles evolved, carrying with them increased heat and violence, while with decreased voltage, the sparks will be finer, not so hot, and they will be emitted with less violence. This action is well illustrated in practice, when butt welding thin sheets, such as No. 20 gage. Permitting the speed of flashing and degree of upsetting to remain constant, and varying the voltage from time to time alone, it has been

FIG. 2—TYPICAL BUTT WELDING MACHINE CIRCUIT

found that pin holes will show up in the seam when excessive voltage is applied. This shows that the violent, volcanic action taking place along the seam has torn out pieces of plastic metal, leaving the edge ragged and toothed, to such a degree that the push up was not able to fill the void spaces made by the violent flashing. However, increasing the degree of upset will in most cases fill up the pin holes again.

Before the effect of increasing the voltage across the weld, comes the further and more important consideration of increasing the speed of acceleration of the metals into the flashing zone, along with the problem of securing the proper degree of acceleration. It has been shown by experimental tests that there is no practical limit to the magnitude of the applied welding e. m. f. advisable to use, so long as the proper degree of acceleration is maintained, and so long as the increased current demand does not produce burning under the dies. In fact the major problem of flash butt welder design, lies in the ability to coordinate the maximum e. m. f. with the maximum degree of acceleration of the metal into the welding zone.

Before proceeding further with the discussion, it is necessary at this time to make a study of the power division of a typical butt welder circuit. A diagram of such a circuit is shown in Fig. 2. Suppose the area of

the steel bar, *A-A*, in the figure to be 1 sq. in.; that its specific resistance is seven times that of pure copper; that the length of the bars, *A-A*, between the dies, *B-B*, is 1 in.; that the length of the welding circuit, external to the dies, *B-B* is 49 in.; and that the area of cross section of the copper parts, *C*, *D*, and *E* is 7 sq. in., (that is seven times the area of the steel bars). With the above proportions, there is, therefore, just the same *I R* drop in the external welding circuit copper, as there is in the bars between the dies, *B-B*. But since in practical designs there are introduced into the external circuit from six to nine electrical joints, all very difficult to make efficient, it is not an infrequent thing to find welding machines where the loss external to the dies is considerably more than the loss internal to the dies. This is especially true if the die contact resistance between die and weldable material be counted in with the external resistance as is usual. With this consideration, many cases are to be found where the internal loss is but 30 per

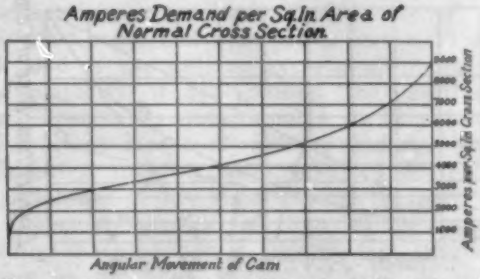


FIG. 3—AVERAGE CURRENT DENSITY IN FLASHING ZONE, FROM BEGINNING OF FLASH TO UPSET

cent of the total welding circuit. This means that a welding machine requiring 100 kw. to make a certain weld, will have a loss of 70-kw. in the external welding circuit, and only 30 kw. loss in the weldable steel between the dies. The internal loss in the steel between the dies is caused by the *I R* drop in the steel, and the counter e. m. f. of the flashing zone. (Whether it is correct to speak of the drop in the flashing zone as a counter e. m. f. may be open for criticism. It seems to act like the carbon arc, and has so been considered.) The magnitude of the loss cannot be definitely stated, since there is a number of variable quantities entering into the problem. The current density is a variable, the specific resistance of the steel varies with its make, and it increases with its temperature, while the counter e. m. f. of the flashing zone is dependent upon the initial e. m. f. impressed, and upon the electrical characteristics of the balance of the circuit. In general, however, approximately ½ volt per inch of length is required to drive welding current density through steel. The counter e. m. f. of the flashing zone may be taken, under average conditions at ½ volt, so that the sum of the resistive drop in one inch length of steel, the counter e. m. f. of the flashing zone, and the die contact, represent approximately 2 volts. If this internal loss represents 30 per cent of the total resistive drop, there will be required an initial impressed e. m. f. of 6.7 volts to overcome the total resistive drop. (The reactive component is not taken into consideration

at this time). The above relations may vary over a wide range, depending upon the design, but in general they will be found in practice to lie somewhere close to the above figures, when taking into consideration only normal and average applications of present welding machines.

To the layman it might appear from the above considerations that resistance butt welding presents a very inefficient method of applying electrical energy. When it is understood that of the 30 per cent energy represented between the dies, only 7½ per cent is used to create or generate the heat in the flashing zone, (1/2 volt is 7 1/2 per cent of the 6.7 volts required to overcome resistive drop), or in other words, but 7 1/2 kw. appears as desired and efficient heat at the welding line, while 92 1/2 kw. is consumed in overcoming unavoidable resistance of the balance of the welding circuit. However, in spite of apparent inefficiency of the welding machine, it stands today as an accomplished fact that resistance butt welding is the cheapest and most rapid method, producing

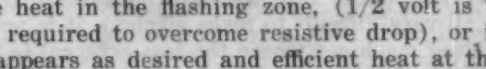


FIG. 4—GRAPHS OF TWO BUTT WELDER FLASH CAMS
Cam *A* produces uniform motion. Cam *B* produces logarithmic acceleration

the most nearly perfect results of all welding methods applied to mass production. An automatic power driven flash pipe butt welding machine welds a 12-in. standard gas or oil line pipe in 7 sec. and consumes 2.7 kw. hr. of electrical energy. This machine produces 40 such complete welds per hour and the machine requires five men in its operation, an average of eight welds per hour per man, the cheapest and most efficient method yet devised for welding together lengths of pipe.

To electrical engineers familiar with the regulative effect of resistance in series with the old time arc lamp, the external losses in the butt welding machine can be largely ameliorated on the grounds of the benefit derived from the regulative effect of external resistance. Take for example an arc operated at 10 amperes, through an external series resistance of 15 ohms, from a 220-volt circuit, having a normal counter e. m. f. at the arc of 70 volts. If the carbons are pulled apart to a point where the current is cut down to 8 amperes, the drop in the external resistance will be cut from 150 volts to 120 volts, leaving an additional 30 volts to be consumed by the arc, or a total of 100 volts at the arc with the 8 amperes flowing as against 70 volts with 10 amperes flowing. This means that a reduction of 20 per cent in current flowing has increased the voltage across the arc by 43 per cent. Hence the stabilizing action of resistance in series with the arc becomes apparent.

In exactly the same manner, external impedance in a welding machine becomes an important regulative factor in stablizing arcing in the flashing zone. In practice, however, it is seldom found necessary to purposely build external impedance into a welding machine, for under the most favorable conditions of design, it is usually sufficiently high. This is especially true of the reactive factor, and every precaution should be taken to cut this factor to the least possible amount. This can be accomplished in a great measure by paralleling as closely as possible the main secondary leads, and avoiding any interlinkage of this circuit with unnecessary parts which will set up a magneto-motive force opposed to the impressed e. m. f.

The power factor of butt welding machines always comes up for consideration. It varies over a wide range, even as wide as the range of application of the machines, ranging anywhere between 45 per cent and 75 per cent. If an average figure were to be hazarded it might be set at 65 per cent. The magnitude of the power factor is not the most important consideration on the part of the designer. It is the power engineer who is most concerned with power factor. The duration of the maximum peak load of the welding cycle is so short, being but a few seconds in the majority of applications, that neither the peak load nor the power factor is as objectionable as they have been thought. It is the universal experience of welding machine engineers, as they go about the country applying machines to industry, that where the nature of the machines is the least known, there is where the power engineers are the most skeptical of their effects to power lines. For example, a welding machine load is welcomed in Detroit, by the Detroit Edison Company as much as any other kind of load, and there is possibly no place in the world where a power company serves more welding machines totaling a greater kv-a.

A study of the current densities found in the normal area of the flashing zone shows that the density does not vary over such wide limits as might be supposed. Of course, if the study is extended to include the beginning of the flash, before normalcy of opposed areas is established, and before normal flashing is established, then the current densities as applied to the whole area, varies from zero to a maximum of approximately 9000 amperes per sq. in., the latter value being that just at upset, and being dependent very largely upon the total impedance of the closed circuit. However, if the study be confined to the densities in the flashing zone, only after normalcy of flashing area has been established the limit of the values is found to lie between 4500 amperes per sq. in. and 7500 amperes per sq. in. as the upper limit. That is to say with any density much below 4500 amperes per sq. in. of weldable steel, flashing will be very feeble, unproductive of heat, while with a value of current density approaching 7500 amperes per sq. in. of area of the flashing zone, a very violent flashing will take place, productive of incandescence, and representing in every way the upper limits of current density. If a fair average value is sought, it may be taken at 6000 amperes per sq. in. of cross section of weldable area. The curve in Fig. 3 shows the range of progress of current density, from the initial flash to the upset.

From the above considerations of the regulative effect of resistance in series with both the arc lamp and the flashing zone of a welding machine, it is apparent that a small increment of increase in the current density is accompanied by more than a direct proportional increment of increase in the necessary impressed e. m. f. It is apparent, therefore, that the power required to butt weld steel as well as other metals, can not be expressed with any degree of accuracy in terms of kilovolt-amperes per sq. in., (kv-a. per sq. in.) with the expectation of the figure

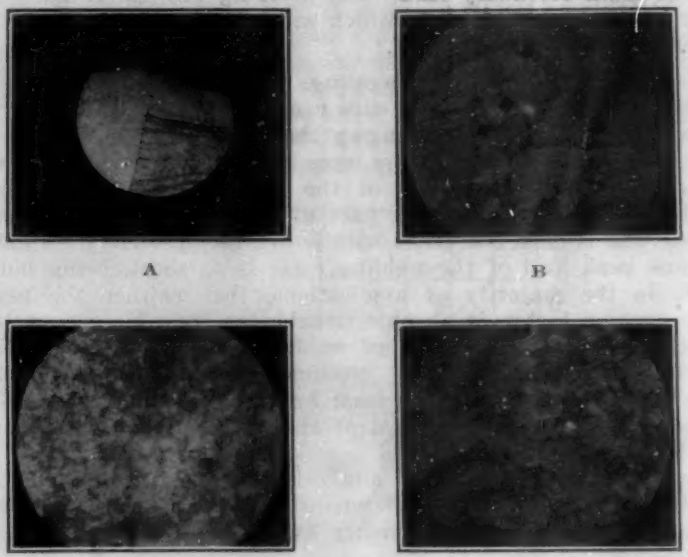


FIG. 5—PHOTOMICROGRAPHS OF PIPE BUTT WELD

A—Complete section, wall of pipe butt weld
B—Complete section, taken to right of weld
C—Taken in the weld
D—Taken to left of weld

holding good for a range of welding machines having different electrical characteristics. While the current density, as for example with steel, does not vary over such wide limits, the e. m. f. required to produce this density does vary over considerable range, depending entirely upon the electrical characteristics of the welding machine. The kv-a. required to weld a given section is dependent upon time. So there are three variables entering into the problem of power required per unit area, *i. e.*, current density, voltage, and time and these three variables do not, as repeated tests have shown, vary by the law of direct or inverse proportions. This statement is especially true of the more recent highly intensified acceleration of the flashing cycle where areas of cross section approximating 16 sq. in. are welded by automatic power welders in, say, six seconds.

The result of feeding metal into the flashing zone of a flash butt weld

is similar to the results obtained by feeding fuel into a furnace. If the furnace is supplied with sufficient oxidizing means, the faster the fuel is fired into the furnace the more heat is generated. This heat will show up in one or both of two ways. It will appear as increased temperature, or it may appear as a large quantity of heat units liberated or as is more probable, it will appear both as increased temperature and as a greater quantity of heat. Similarly with a flash butt weld, if sufficient welding e.m.f. is maintained, the faster the metal is fed into the flashing zone, the greater will be the heat set up. This will show up as increased temperature and also in the larger quantity of heat units produced, part of which is carried away by the flashing materials thrown off, part of which is carried away by convection due to the higher temperature gradient, and a small part of which is directly radiated away.

The critical part of the flashing cycle is usually found to be at the beginning. If sufficient energy is available to start the flashing at uni-

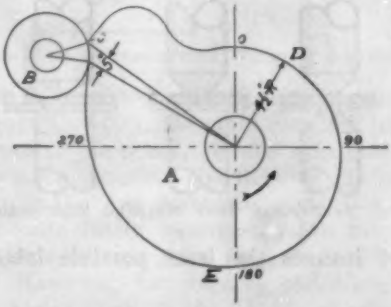


FIG. 6—TYPICAL COMBINATION FLASH AND UPSET CAM, USED FOR SMALL CROSS-SECTIONS

form speed until normalcy of areas is presented, there is little danger from cessation of flashing, due to freezing at points later on in the flashing cycle. The flashing cam used in the average automatic butt welding machine seldom has an acceleration greater than 3 : 1. In a few extreme instances the acceleration approaches 3½ : 1. It has recently been found that a very much greater ratio of acceleration is possible. The larger ratio is not only possible, but very desirable if not necessary. In Fig. 4, are shown graphs of two cams, *A* and *B*. The cam, *A*, is constructed with equal increments of rise for equal increments of angular movement. In other words it is a straight line, forming an angle, β, with the horizontal base line. The cam, *B*, is a logarithmic curve. It is constructed so that the tangent θ, is approximately eight times greater than the tangent, $\triangle$ thus producing a final acceleration, eight times greater than the initial speed. The initial movement is taken at the same maximum speed insuring against freezing. The tangent of the angle, $\triangle$, in this graph is 0.192, while the tangent of the angle, β, is 0.5151. Therefore if cam *A* is to replace cam *B*, the angular velocity of cam *A* will have to be slowed down in the inverse ratio of 0.192 : 0.515, or in the ratio of 2.68 : 1. Therefore from a standpoint of time, the cam, *B*, will perform a given flashing cycle in 7½ sec., while cam, *A*, will require 20

sec., to perform the same flashing cycle. The saving in time by the use of the form of cam, *B*, over that of *cam*, *A*, is only a part of the benefits derived by its use. The saving in time is in fact only incidental. The benefits lie in the shortened time of the flash produced by the high acceleration of the metals into the flashing zone, which in turn produces the maximum degree of temperature in the shortest possible time, providing the least possible "run-back" of heat. From these two conditions are derived two important results. The first is, that maximum degree of heat with momentary duration, positively insures a fine grain structure in the weld. It further insures a thin lamination effected by the weld, in most cases not exceeding 0.001 in. thickness. And in the second place a short "run-back" of heat insures a small swelling at the upset. The former condition, a fine grain structure in the weld, insures a tensile and bending strength equal to or greater than the virgin metal; while

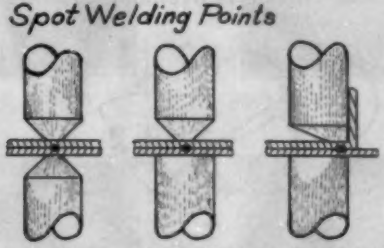


FIG. 7—TYPICAL SPOT WELDING ELECTRODES

a short quick upset insures the least possible labor in removing the excess material.

The photomicrographs in Fig. 5 show an automatic pipe butt weld made in six seconds, the wall of the pipe being ⅜ in. thickness. Graph *A* of Fig. 5 is of low power and is intended to be a bird's-eye view of the whole section. Graph *B* is of higher magnification, showing the virgin structure of the pipe to the right of the weld. Graph *C* is of the same magnification showing the grain structure in the weld, while Graph *D* shows the grain structure to the left of the weld. Hundreds of photomicrographs have been made of this type of weld, and all show the same fine grain structure in the weld. This condition can seldom be secured by slow flashing and upsetting.

The time required for upsetting is as important as the degree of acceleration and the time required for the flashing cycle. Here again, tests have shown that the quicker and sharper the upset action has been, the more complete and perfect has been the fusion in the weld. If the upset is made slowly, it must then be forced to a much greater degree to form a good weld, and the weld will be accompanied by an objectionable amount of squeezed out material. It is evident from a study of welds made with varying lengths of time in upsetting, that the instant the abutting pieces touch, and flashing is stopped, the temperature drops on the inner surfaces of the weld. The high degree of temperature necessary for fluidity and perfect fusion evidently falls the instant flashing ceases, and it does so whether the welding current is held on during the upset cycle or not. In automatic pipe butt welding, where areas as large as 16 sq. in. are

being welded, it has been found that if the upsetting can be done in 0.1 sec. or less the required grain structure in the weld is preservd.

It is difficult to design a combined flashing and upsetting cam to weld the larger areas. Two problems are presented. The first problem is to be able to make the comparatively slow moving flashing cam perform the upset in the short space of time, and the second problem is to be able to design this slowly moving cam so it can exert the necessary foot pounds required to upset the weld. Take for example a combined flash and upset cam shown in Fig. 6. If such a cam is designed to flash and upset 3 sq. in. of steel, it may be found advisable to make the minimum radius about 4½ in. Permitting an idle zone from *O* to *D*, the active flashing portion of the cam extending from *D-E* and *C*, will cover about

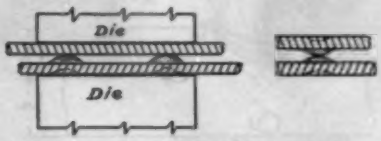


FIG. 8—METHODS USED IN PROJECTION WELDING, SHOWING ELECTRODES

270 deg. If the cam is provided with ½ in. of upset at *C*, and the cam roller is 4 in. minimum diameter, the main cam will have to turn approximately 5 deg. to complete the upset. If the upset takes place in 0.1 sec., it will require 5.4 sec. to complete the flashing cycle, (270 deg.) or 7.2 sec. for the cam to make one complete revolution. The cam chosen probably illustrates quite fairly average design proportions for a combination flashing and upsetting cam used on welding machines up to 3 sq. in. capacity. However, for welding considerably larger sections, even three or four times that of the above, or where for example an area of 36 sq. in. must be flashed and upset automatically, the above combination cam can no longer be made to meet the necessary requirements. Heretofore all such sections have been flash butt welded by hydraulic power. To accomplish this by motor power fully automatic, it has been found necessary to introduce into the welding machine two systems of cams. One system is confined to the flashing cycle, and the other is confined to the upsetting cycle. The flashing cycle requires, inherently, from fifty to one hundred times more time than the upsetting cycle. At the same time it requires only a fractional part of the energy required for upsetting. When the two systems are used the upsetting cam is timed or synchronized with the flashing cam. With this arrangement the speed of the flashing cam can be varied at will, or the amount of the flashing cam permitted to become operative can be varied without affecting the time of the upset cycle. The amount of flashing, of course, is dependent upon the relative time that the upset cam functions. Two large butt welding machines have been constructed along this line, one welding up to 16 sq. in., and the other welding up to 36 sq. in., and both have proved beyond doubt the correctness of the principle. (This feature is being protected by patents.)

II. SPOT WELDING

Spot welding, while not so old as butt welding, has now been practised for many years, and it is accomplished essentially by the use of two

copper electrodes, variously formed as in Fig. 7. The electrodes thus formed are on opposite sides of overlapping sheets, and a powerful current of short duration is passed from electrode to electrode, passing through the sheets. The magnitude of the current is so proportioned that the sheets are heated to plasticity, whereupon an extra force is exerted upon the sheets by the electrodes and they are forced together and thus welded. The area thus welded is usually small, ranging from ⅛ in.

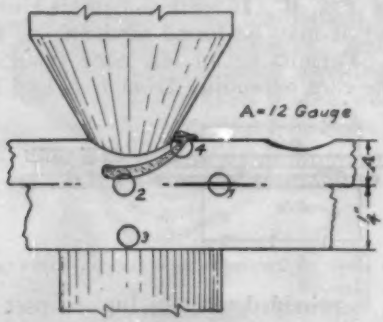


FIG. 9—PLAT OF PHOTOMICROGRAPHS, TYPICAL SPOT WELD

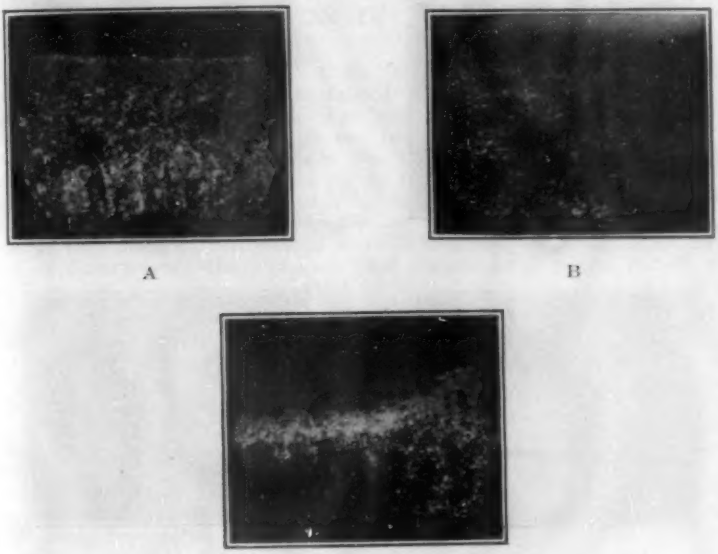
diameter up to extreme diameters of about ½ in., depending upon the plate thickness, quality of plate, etc.

The current density required for welding by this method varies much with the thickness of the sheets, quality of the sheets, diameter of the points, and the time of duration. For a rough comparison between spot welding and butt welding a factor of 20 might be taken as giving fair average conditions. That is to say a current density of about 120,000 amperes per sq. in. of spot weld area is required. This figure can be used only for rough calculations, and a closer figure can be given only by one experienced in these requirements.

An improvement over the old method of spot welding has come into use, known as projection welding. In this case plain flat electrodes are used above and below the sheets to be welded, as in Fig. 8. Before welding, one or both of the plates are projected by a forming die. At the left in Fig. 8 only one plate, the lower one, is projected, while at the right both plates are projected.

The essential thing to secure in both spot welding and projection welding is proper heat control. A large majority of these welds either show burning or they are overheated to such an extent as to show a very poor grain structure. Fig. 9 shows diagrammatically a typical weld between a No. 12 gage polished cold rolled sheet and a ¼-in. cold rolled sheet. The upper electrode was pointed, while the plates rested upon a flat lower electrode, both shown in part only. Photograph A in Fig. 10 was taken at (1) in Fig. 9. It shows the longitudinal laminations caused by rolling the sheet. The upper dark band is the small open space between the sheets darkened by the copper etching solution. Pho-

tograph B taken at position (3) low down in the sheet next to the lower electrode, shows overheating, poor arrangement of grain structure, and even burning. Position (2) was very similar to position (3), and for brevity has been omitted. Photograph C of position (4) taken right under the upper electrode, shows the cooling effect of contact with the upper electrode by the band adjacent to it, leaving the rolling laminations



A B C

FIG. 10—PHOTOMICROGRAPHS OF FLASH WELD
A—Showing virgin sheet at position (1) in Fig. 9
B—Showing effect of current, position (3)
C—Showing effect of current, position (4)

plainly visible. Overheating is shown lower down, however, and in the extreme lower corner burning is in evidence.

The recently developed methods of "flash spot welding," and "flash projection welding," entirely eliminate all tendency toward burning, and insure a fine grain structure, accompanied by an entire rearrangement of crystals of the most favorable nature. The photomicrographs in Fig. 11 show typical flash projection welds made between two twelve-gage cold rolled sheets. Three of these photographs show the same weld using three different powers of magnification. These three were taken without changing the axis of the field of the microscope. The microscope was focused at the very extreme edge of the weld. The curved shape of the projection is plainly visible.

Flash spot welding and flash projection welding accomplish in this field, exactly what the rapidly accelerated flash and quick upset accomplish in the field of butt welding. Both are dependent upon the theory that high heat, quickly secured, and held for a short duration only, will invariably produce a fine-grain structure in the weld.

III. Seam Welding

It is not felt necessary to go into the theory or application of seam welding at this time. The process in short is a refined application of spot welding. In place of pointed electrodes, as in spot welding, the electrodes are usually formed like wheels. These wheel electrodes are

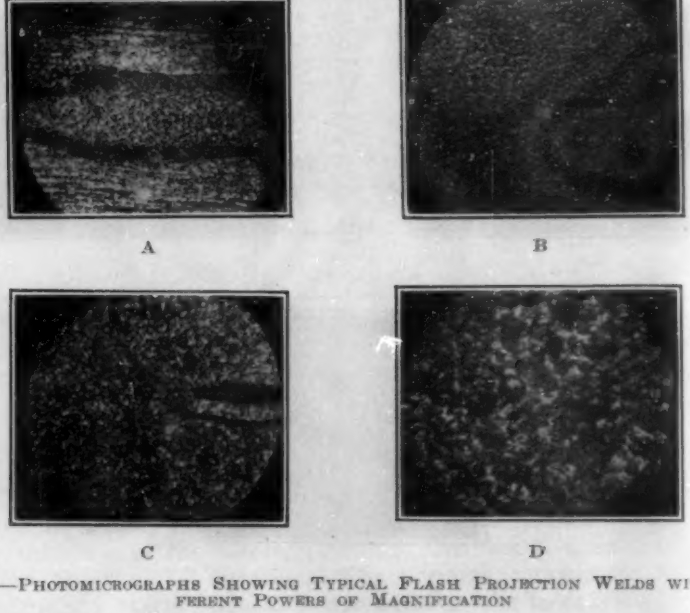


Fig. 11—Photomicrographs Showing Typical Flash Projection Welds with Different Powers of Magnification

caused to roll on opposite sides of overlapping plates, and a rapid succession of welds is made in this way. The circuit may be interrupted rapidly by mechanical means, as is usually the case in welding stock coated with scale or otherwise unclean, while in welding polished cold rolled sheets it is quite generally the practice to omit the interruption of the circuit, depending in this event upon the cyclic interruption caused by the alternating current. The process in general finds application in welding cans, automobile gas tanks, and various other receptacles of this kind. A highly refined application of seam welding is to be found in the manufacture of light wall steel pipe and tubing. In this application a mechanical means of interruption is not resorted to. Entire dependence is placed upon the cyclic values of the alternating current. The process has recently been speeded up by the use of frequencies higher than those used for power purposes. In this application each alternation forms a weld or "stitch." The metal is passed at a speed which causes the welds to overlap just enough to insure a completely welded seam.

The author desires to thank Mr. Paul C. Zarrs, Chief Engineer, The General Welder Company, for valuable suggestions, and for assistance in producing the photomicrographs herewith shown.

Recommended Procedure for Fusion Welding of Pressure Vessels

"The Unfired Pressure Vessel Code issued by the American Society of Mechanical Engineers in 1923 contained but limited provisions for welded construction in pressure vessels. For welded construction, it was provided that the diameter be limited to 20 in., the working pressure to 100 lb., and the maximum unit working stress in the welded joint to 5600 lb. per sq. in., except that in the circumferential joints a somewhat more liberal allowance was given. The answer of the A.S.M.E. Boiler Code Committee to all requests for a liberalization of these welding rules has uniformly been that it could not see its way clear to recommend such liberalized rules until some practical method of determining the elements that ensure safe, sound welds could be found.

"In 1927, a special committee was appointed to investigate ways and means of accomplishing what the Boiler Code Committee has so long desired for control of good welding. The work of this committee bore fruit late in 1928, when it reported on a Recommended Procedure for Fusion Welding of Pressure Vessels; this Recommended Procedure contained specifications for the following items in welded construction: (I) Materials, (II) Design, (III) Construction, (IV) Qualification of Welders, (V) Supervision, (VI) Inspection, and (VII) Testing. The report was accepted by the Board of Directors of the American Welding Society, and submitted to the A.S.M.E. Boiler Code Committee in January, 1929, with the assurance that if the above seven elements were properly controlled, sound and safe welded joints would be obtained with certainty.

"When the Recommended Procedure was submitted to the Boiler Code Committee, it was accepted as an important advance in the application of fusion welding to pressure vessel construction, and a revision of the welding rules in the Unfired Pressure Vessel Code was begun. This revision work was completed late in 1929, and the text thereof, together with the Recommended Procedure, is presented herewith."—Above Editorial Note Prepared by Mr. C. W. Obert.

Revisions and Addenda to the Boiler Construction Code

IT is the policy of the Boiler Code Committee to receive and consider as promptly as possible any desired revision of the Rules and its Codes. Any suggestions for revisions or modifications that are approved by the Committee will be recommended for addenda to the Code, to be included later on in the proper place in the Code.

The Boiler Code Committee has received and acted upon a number of suggested revisions which have been approved for publication as addenda to the Code. These are published below, with the corresponding paragraph numbers to identify their locations in the various sections of the Code, and are submitted for criticisms and comment thereon from any one interested therein. Discussions should be mailed to the Secretary of the Boiler Code Committee, 29 West 39th Street, New York, N. Y., in order that they may be presented to the Committee for consideration.

For the convenience of the reader in studying the revisions, all added matter appears in small capitals and all deleted matter in smaller type inclosed in brackets.

Proposed Revisions

PAR. U-23 REVISED:

U-23. Pressure vessels shall not be fabricated by means of fusion welding under the rules given in Pars. U-67 to U-79 except:

a Air vessels, when the diameter does not exceed 20 in., the length does not exceed 3 times the diameter, and the working pressure does not exceed 100 lb. per sq. in.

b Other vessels, under these rules, in which the circumferential joints only may be welded, when the inside diameter does not exceed 48 in., or 72 in. when at least 75 per cent of the load on a flat head is supported by tubes or through stays extending from head to head.

C WHERE THE VESSELS ARE FABRICATED IN ACCORDANCE WITH THE RECOMMENDED PROCEDURE FOR FUSION WELDING OF PRESSURE VESSELS GIVEN IN THE APPENDIX, THE LIMITING DIAMETER IN PAR. U-23*A* MAY BE TAKEN AS 60 IN. AND THE LIMITING PRESSURE MAY BE TAKEN AT 200 LB. PER SQ. IN., PROVIDED THE TEMPERATURE DOES NOT EXCEED 250 DEG. FAHR.

PAR. U-68 REVISED:

U-68. WHEN WELDED IN ACCORDANCE WITH THE RECOMMENDED PROCEDURE FOR FUSION WELDING OF PRESSURE VESSELS GIVEN IN THE APPENDIX, THE STRENGTHS OF JOINTS MAY BE CALCULATED ON A MAXIMUM UNIT WORKING STRESS (*S*), AT RIGHT ANGLES TO THE DIRECTION OF THE JOINT, AS FOLLOWS:

FOR BUTT DOUBLE V LONGITUDINAL WELDS	8000 LB.
FOR BUTT SINGLE V GIRTH OR HEAD WELDS	6500 LB.
FOR DOUBLE FULL FILLET LAP OR GIRTH WELDS	7000 LB.
FOR SPOT OR INTERMITTENT GIRTH OR HEAD WELDS	5600 LB.

UNLESS THE PROCEDURE FOR FUSION-WELDED VESSELS GIVEN IN THE APPENDIX IS FOLLOWED IN ALL PARTICULARS [when properly welded by the fusion process] the [strength of a joint may be calculated on a maximum] unit working stress (*S*) AT RIGHT ANGLES TO THE DIRECTION OF THE WELD SHALL NOT EXCEED 5600 lb. per sq. in. (see Par. U-20).

Recommended Procedure for Fusion Welding of Pressure Vessels

IT is the purpose of this statement to outline such a course of procedure, embracing the essentials of proper fusion welding, as will not only insure sound and safe welded construction for pressure vessels, but will also enable such results to be duplicated at any place and at any time. This procedure outline is general in character and contemplates the use of any of the established methods of fusion welding, either hand or

machine, for the construction of pressure vessels. The subject-matter is presented under the following subdivisions:

I	Materials	V	Supervision
II	Design	VI	Inspection
III	Construction	VII	Testing
IV	Qualification of Welders		

I—MATERIALS

Plate for Shell, Heads, Etc. Steel plates for any part of a vessel that are subject to stress produced by internal pressure and are welded shall be of good weldable firebox or flange quality conforming to the Specifications for Steel Plate of Flange Quality for Forge Welding, as given in Pars. S-264 to S-279, or to the Specifications for Steel Boiler Plate in Pars. S-5 to S-17 of Section II of the Code.

Material for Manholes, Nozzles, and Other Connections. Material for manholes, nozzles, and other connections which are to be joined to the shell or heads by fusion welding, shall, when forged or rolled, comply with the specifications given for shell plate and heads as to chemical and physical properties, and be of good weldable quality. Steel castings and commercial nozzles may be used only when the material has been proved to be of good weldable quality.

Filler Material. Welding wire, rods, and/or electrodes must be smooth and free from scale, rust, oil, or grease. In the hands of an experienced welder, the filler material shall demonstrate good weldability and shall flow smoothly and evenly without any unusual characteristics.

Electrodes for metal arc welding of all kinds shall conform to the American Welding Society Specifications E1A or E1B.

Welding rods for gas welding shall conform to the American Welding Society Specifications G1A.

Other welding rods, wire, and/or electrodes may be used provided they give results equal to or better than those specified in Section IV.

II—DESIGN

The design of all pressure vessels shall conform to the various requirements of the Code for Unfired Pressure Vessels. In applying the rules of this Code, however, care should be taken to proportion and so place the constituent parts of the vessel that due consideration may be given to the requirements of the welded joint. In all cases where plates of unequal thicknesses are butted, it is desirable to reduce the edge of the thicker plate in some manner so that it is approximately the same thickness as the other plate; this is an exceedingly important element in obtaining complete fusion and should be treated as one of the factors contributing to a sound and safe welded joint. Furthermore, in the design of welded vessels care should be taken to so locate the welded joint that the bending stresses that are inevitable in certain shapes of structures will not be brought directly upon the welded joint; as an instance may be cited the case of dished heads on cylindrical vessels, in which the weld should not be applied directly at the knuckle of the head. Corner welds should, in

general, be avoided unless the plates forming the corner are properly supported independently of such welds. Lap joints should be avoided for heavy stresses or for the joining of thick plates. In general, welds in tension or shear are much to be preferred over those subjected to other forms of stress. The design of parts of cylindrical vessels other than the shell should be so controlled that satisfactory welded design is assured and that the vessel will have uniform strength throughout; this applies particularly to large outlets and manhole openings.

III—Construction

Preparation for Welding. The plates or sheets to be joined shall be accurately cut to size and formed. In all cases the forming shall be done by pressure and not by blows, including the edges of the plate forming longitudinal joints of cylindrical vessels.

Bars, jacks, clamps, or other appropriate tools may be used to hold the edges to be welded in line. The edges of butt joints must be so held that they will not be allowed to lap during welding.[1] For plates in excess of ¾ in. thickness, the offset must not be more than 10 per cent (maximum ¼ in.) for girth seams. Where fillet welds are used, the lapped plates shall fit closely and be kept tight together during welding.

The surfaces of the sheets or plates to be welded must be cleaned thoroughly of all scale and rust for a distance of about ½ in. back from the welding edge. A steel-wire scratch brush may be used for removing light rust or scale, but for heavy scale, slag, and the like, a grinder, chisel, air hammer, or other suitable tool should be used that will clean down to bright metal. When it is necessary to deposit metal over a previously welded surface, any scale or slag therefrom should be removed by a roughing tool, a chisel, an air chipping hammer, or other suitable means to prevent inclusion of impurities in the weld metal. In case there is grease or oil on the welding edges, it should be thoroughly cleaned with gasoline, lye, or the equivalent.

Welding Method. The application of this welding procedure is not limited to any method or process of welding or to any particular materials, but it is essential that the method or process shall be capable of effecting thorough fusion of the weld metal to the edges to be joined. There are no limitations as to the preparation of the edges to be welded except as provided in Par. U-71 of the Code that for the longitudinal joints of cylindrical vessels, double-V-type welds must be applied. It is here pointed out that while Par. U-71 requires for double-V welds penetration half-way through from each side, a well-made single-V weld which is reinforced at its root is considered to be satisfactory. In cases when fusion at the root is irregular, the root of the weld shall be chipped out before reinforcing.

The dimensions and shape of the edges to be joined shall be such as to allow thorough fusion and complete penetration.

As full and complete penetration of the weld metal through the entire thickness of the plate is essential for safety, considerable precaution must

[1] Attention is called to the requirement in Par. U-71 of the Code that stipulates that the sheet on one side of the joint must not be allowed to offset from opposite sheet by more than one-quarter of their minimum thickness.

be taken to insure this result. If the welding is stopped for any reason, extra care must be taken, when restarting, to get full penetration to the bottom of the joint and thorough fusion between the weld metal and the plates and to the weld metal previously deposited.

In double-V butt welds the edges to be joined shall be so separated that the weld metal can penetrate to the root of the V.

Before welding the second side of the double-V, all scale and metal which has run through from the weld on the first side must be removed by some suitable method such as by chipping or grinding, and the rust removed from the adjacent surfaces for ½ in. back. Any suitable means such as a round-nosed chisel may be used to remove the metal from the V, and a portable grinder to clean the scale from the plates.

When single-V joints are used, particular care must be taken in lining up and separating the edges to be joined so that complete penetration and fusion at the root of the V will be assured, for in some instances it will be impracticable, to eliminate any lack of fusion by reinforcement of the opposite side—for example, on head seams of tanks less than 3 ft. in diameter and containing no manhole.

Particular care should be taken in the layout of joints in which fillet welds are used so as to make possible the fusion of the weld metal at the bottom of the fillet. Great care must also be exercised in the deposition of the weld metal so as to secure satisfactory penetration.

Reinforcement and Finish. The reinforcement of welds shall, in accordance with the requirement of Par. U-71 of the Code, be built up uniformly from the edge of the plate to the maximum at the center of the weld. Particular attention is called, however, to the importance of the provision in that rule that there shall be no valley or groove along the edge or in the center of the weld, but that the deposited metal must be fused smoothly and uniformly into the plate edge at the top of the V.[2] The finish of the welded joint must be reasonably smooth and free from irregularities, grooves, or depressions.

If a cylindrical shell shows irregularities after welding, it shall be rerolled to render it truly cylindrical, or the ends may be heated and shaped to come within the following limits:

The edges of the plates at the seams shall not offset from each other at any point in excess of one-quarter of the thickness of the plate, except for plates in excess of ¾ in. in thickness, in which the offset must not be more than 10 per cent (maximum ⅛ in.) for longitudinal seams, or 25 per cent (maximum ¼ in.) for girth seams.

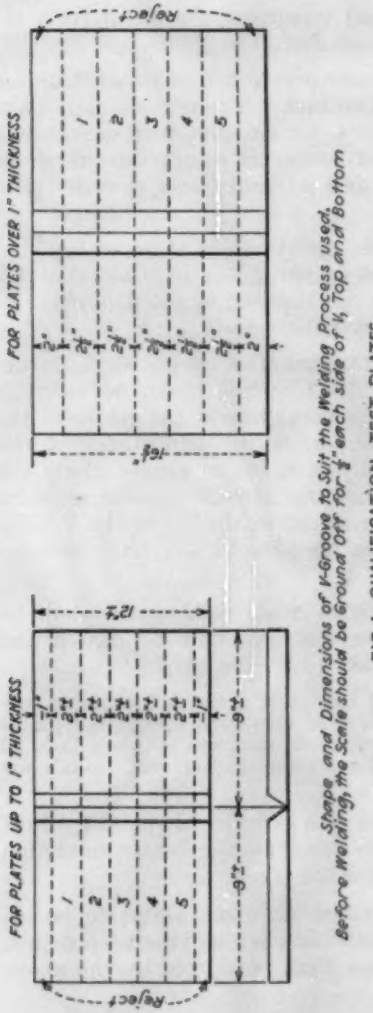
If the thickness of a head to be attached to a cylindrical shell by a butt joint exceeds the shell thickness by more than 25 per cent (maximum ¼ in.), the head thickness shall be reduced.

Heads concave to pressure and plate edges at girth seams to be attached by butt joints shall be lined up with the shell as true as possible, dividing up any offsets. If these are more than permitted by the above

[2] If the reinforcement is built up so as to form a ridge with a valley or depression at the edge of the weld next to the plate, the result is a notch which causes concentration of stress and reduces the strength of the joint.

limitation, corrections shall be made by reforming the shell or head, whichever is out of true, until the errors are within the limits specified. The sheets at head and girth seams shall be kept so spaced that they shall be separated at the point of welding enough to insure thorough penetration of the weld metal.

Heads convex to pressure shall, as prescribed in Par. U-74 of the Code, be prepared and applied with a length of flange of not less than 1 in.



Shape and Dimensions of V-Groove to Suit the Welding Process used. Before Welding, the Scale should be Ground Off for ½" each side of ½ Top and Bottom

FIG. 1 QUALIFICATION TEST PLATES

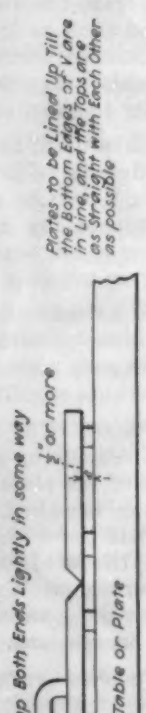

Plates to be Lined Up Till the Bottom Edges of V are in Line, and the Tops are as Straight with Each Other as possible
Clamp Both Ends Lightly in some way
1" or more
Iron Table or Plate

FIG. 2

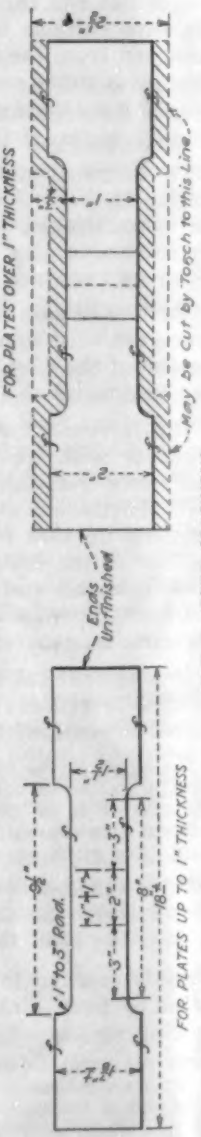


FIG. 3 TEST SPECIMENS

for shells not over 24 in. in diameter, but of not less than 1½ in. for shells over 24 in. in diameter. It is recommended in the Code that this length of flange be made not less than 12 per cent of the diameter of the shell.

IV—Qualification Test for Welders

The qualification test will consist of welding together in a flat position two plates of the same material and thickness as are to be used in the tank under consideration (see Fig. 1). Should the welder be required to make fillet welds, butt welds over ⅜-in. thick, or welds in other positions than in the flat, he shall qualify in that class of work. If a backing strip be used in practice for single-V butt welds, it may be employed in making the test specimens. After cleaning and straightening the plates and machining the edges to be welded, they shall be clamped down and the edges of the V lined up (see Fig. 2). It is important that the edges of the V shall not lap during welding and thus prevent full penetration. To this end the plates shall be so spaced before starting the weld that, at the point of welding, there shall be a slight distance between the edges of the V.

The test plates shall be cut up as shown in Fig. 1 by the dotted lines and the two outside strips rejected because they may not be truly representative of the weld. This cutting may be done with a gas cutting torch. Pieces 1, 3, and 5 shall be machined as shown in Fig. 3. The reinforcement should be ground or machined off both sides. The last grinding or tool marks should be parallel with the length, and not at right angles to it.

The test specimens shall then be tested in a tensile testing machine to determine the ultimate strength in pounds per square inch.

The ultimate strength determined by tensile test will be the basis for the welder's rating. In order for him to qualify, the tensile-strength results should average at least 45,000 lb. per sq. in., with no one test piece giving less than 42,000 lb. If these results are not reached, the welder may be given a duplicate test. If the welder successfully passes this test, he shall be considered qualified.

The record of a welder's qualification test should contain complete information concerning the material of the plate welded, the filler metal used, the type of welding equipment, any pertinent particulars concerning its operation, and the quality of the weld not only as to completeness of fusion with the base metal but also as to completeness of penetration. Any peculiarities of the weld should also be noted such as finish and surface defects, style and amount of reinforcement, and appearance of weld on underside at bottom of V.

V—Supervision and Local Inspection in Shop

The welding supervision constitutes the system of oversight and shop inspection which insures that the provisions for proper Materials (1), proper Design (2), proper Construction (3), and properly Qualified Welders (4), shall so cooperate as to give sound and safe welded construction. It is the duty of the management of the welding shop to provide such supervision and local inspection as will make sure that the requirements of the Code for Unfired Pressure Vessels and also those of

this Recommended Procedure will be carried out on any welded pressure vessels to be stamped as provided for in the Code.

It is preferable, although not essential, that those who are charged with this supervision shall have a practical knowledge of fusion welding, particularly with the process that is employed. The supervisor shall provide and have readily accessible for purposes of record necessary data concerning the material, designs, qualifications of welders, etc. The assent to and signature upon the manufacturer's data report by the manufacturer's representative constitute a guarantee that the vessel conforms to the requirements of the Code for Unfired Pressure Vessels.

Any local inspection that may be provided in the manufacturer's shop must be arranged to function without possible interference with the work of the authorized inspector from the outside and employed under the terms of Section VI. Such local inspection would obviously be operated as a service of the manufacturer to check the employees and make sure that they are carrying out all instructions and the details of this procedure.

VI—Inspection

The manufacturer shall arrange for inspection of the pressure vessels during construction, as provided for in Par. U-65 of the Code. The inspector employed for this purpose shall not be in any way connected with the management of the shop performing the welding, but shall be a state or municipal inspector or an inspector regularly employed by an insurance company engaged in boiler or pressure-vessel inspection work.

It shall be the duty of the inspector to check the construction of the vessel to make sure that the provisions of this Recommended Procedure are carried out. He must arrange his inspections covering materials, design, and construction to conform to Code requirements, and the qualification of welders to meet the convenience of the supervisor or other representative of the manufacturer, and be prepared to sign the data report furnished by the manufacturer. He must direct particular attention of the manufacturer to the requirements for testing of welded vessels in Par. U-78 of the Code.

Inspection of Material. The inspector shall satisfy himself that all material used in the manufacture of a vessel is in accordance with the Code requirements, and if he desires he may secure from the manufacturer a written statement to the effect that it is, to the best of his knowledge and belief, in accordance with the Code. All parts shall be examined whenever possible before they are assembled as well as after they are applied. Material having injurious defects as referred to or defined in the Code shall be rejected.

The inspector shall see that plates are properly stamped before being used. Should the identifying marks be obliterated or plates separated into two or more parts in the process of work, he shall see that such marks are properly transferred under Code requirements.

All material shall be gaged or measured to determine whether the thickness meets with the Code requirements, due allowance being made for Code variations. During the process of manufacturing a vessel, the

material shall be inspected for surface defects, cracks, blisters, pit marks, blowholes, or any other defects liable to develop in fabrication, and for excessive hammer marks. If defects are sufficient to materially impair the strength, the vessel shall not be stamped with the Code marking. If depressions are found, careful measurement shall be made, and if by reason of the reduced thickness the plate is not weaker than where machined for holes or openings for connections and outlets, it may be accepted, provided that in no case shall a plate be accepted having a depression greater than 15 per cent of its thickness and not exceeding 4 in. in its greatest length. Plates that are found laminated shall be rejected.

All cast parts when ready for use shall be carefully examined to determine that the walls are not less than the designed thickness, free from injurious defects, and annealed as required by the Code. All lugs, brackets, nozzles, flanges, manhole frames, and other appurtenances shall fit snugly and conform to the curvature of the shell or surface to which they are attached.

After the shell is welded, the inspector shall inspect the welds from the inside and the outside of the shell and record their appearance. Before examining a weld, the outside and inside of the shell shall be struck all along the length of the weld with a hand hammer to break loose the scale. A wire brush shall also be used to clean the surfaces. Double-V welds shall be hammered the same as single-V welds.

In any case low spots in or at the sides of the weld may be filled up as in the case of pinhole repairs. If the low spots are not longer than four times the thickness of the plate, and if they do not go below the surface of the plate, they need not be repaired.

VII—Testing

After welding has been completed and the vessel has cooled and is ready for testing, it shall be given the hydrostatic pressure test as prescribed in Pars. U-65 and U-78 of the Code. The water used for testing shall preferably be of a temperature not less than that of the surrounding atmosphere, or at least not under 70 deg. fahr.

Care shall be taken in filling the vessel to set it up with one of the outlets on top and leveled so that all of the air therein can escape when it is filled with water. A test gage shall be connected to a suitable outlet on the vessel which shall preferably read to approximately double the maximum hydrostatic pressure. The connection to the gage should be fitted with a cock or valve so as to prevent the shock of hammer testing from being communicated to the delicate gage mechanism.

The pressure shall be slowly raised until it meets with the Code requirements for the type of vessel under test, and shall be held there long enough to enable the inspector to examine all visible parts. If the tank is entirely free from leaks under these tests, it shall be accepted by the inspector, who shall certify thereto on the data report form. If leaks occur, they may be repaired in the following ways:

Pinholes, except on longitudinal seams, may be calked, filled with a plug not to exceed ¼ in., or welded by the metal-arc process without pre-

heating, or they may be melted out and rewelded by any process, provided the metal around the pinhole is preheated to a dull red for a distance of at least 4 in. all around it. Any preheating means may be used, such as a flange fire, gas or oil burner, or a welding torch. The preheating should be done slowly, so the heat will get well back into the plate and expand it thoroughly. After welding, the tank should be reheated in the vicinity of such weld until the heat has equalized in the dull red spot, and then slowly cooled.

Pinholes in longitudinal seams must be repaired only by cutting or melting out the defect and rewelding with the above precautions in regard to preheating and reheating, except that with metallic-arc welding, preheating and reheating are not required. Cracks in welds shall only be repaired by cutting out the weld and rewelding the entire seam.

After repairs have been made, the tank shall again be tested in the regular way, and if it passes the test the inspector shall accept it. If it does not pass the test the inspector can order supplementary repairs, or if in his judgment the tank is not suitable for service he may permanently reject it.

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